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Design, Construction, and Maintenance of Cover Systems for Hazardous Waste
An Engineering Guidance Document

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DESIGN, CONSTRUCTION, AND MAINTENANCE OF COVER SYSTEMS FOR HAZARDOUS WASTE

AN ENGINEERING GUIDANCE DOCUMENT

by

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16. ABSTRACT

Engineering for cover over solid hazardous waste addresses complex interactions among many technical, environmental, and economical factors. This document emphasizes the special characteristics of solid waste management as they bear on the cover system while at the same time stressing the need for engineering experience to integrate the complex factors into the traditional engineering approach.

Cover systems typically consist of two to four layers of soil and other materials and resemble a highway pavement system in many respects. This similarity facilitates the preparation and use of construction and maintenance specifications, examples of which are provided.

Engineering analyses and design techniques are discussed for percolation, erosion, stability, flooding, freezing, and settlement. Finally, guidance is provided on methods of maintanance and repair over the unusually long design life of a solid waste disposal facility.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of the State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

The user of this document should carefully read the Introduction to understand the approach and the strengths and limitations. Simply characterized, the guidance is designed primarily to be used in combination with engineering expertise rather than for stand-alone use by any scientist or technician. Therefore, the strengths of this document lie in its marshaling together appropriate engineering practice, methods, and standards already familiar to the broadly trained and experienced construction engineer. Somewhat speculative phenomenology is carefully avoided. Nevertheless, the guidance is recommended for scientists and for inexperienced engineers provided their participation in or influence on actual design, construction, and maintenance is not overextended.

In preparation of this document, several experience bases were reviewed for pertinence to hazardous waste disposal practices. Among these sources of experience were highway construction, land reclamation, earth work construction, general geotechnical engineering, and low-level radioactive waste disposal. Although radioactive waste is regulated by the Nuclear Regulatory Commission rather than EPA, the somewhat similar potential threats of land-disposed low-level waste make that experience of more than incidental technical interest.

Thomas G. Hauser, Director
Hazardous Waste Engineering Research
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ABSTRACT

Engineering for cover over solid hazardous waste addresses complex interactions among many technical, environmental, and economical factors. However, the engineering approach developed over the years in general earthwork and in highway construction provides a framework by which the special viewpoint of solid waste management can be accommodated. Accordingly, this technical resource document emphasizes the special characteristics of solid waste management as they bear on the cover system while at the same time stressing the need for engineering experience to integrate the complex factors into the traditional engineering approach.

Cover systems typically consist of two to four layers of soil and other materials and resemble a highway pavement system in many respects. This similarity facilitates the preparation and use of construction and maintenance specifications. Example specifications are provided in the appendices.

Criteria and methods are available for engineering analyses of percolation, erosion, stability, flooding, freezing, and settlement. Techniques are available for compensation for each of these threats, again using recognized design and construction methods. Finally, guidance is provided on methods of maintenance and repair over the unusually long design life of a solid waste disposal facility.

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METRIC CONVERSION TABLE

Multiply	By	To Obtain
acres	4046.856	square meters
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
degrees (Fahrenheit)	5/9*	degrees Celsius or Kelvins*
feet	0.3048	meters
gallons (US liquid)	0.003785412	cubic meters
inches	0.0254	meters
mils	.0000254	meters
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.1120851	grams per square meter
pounds (mass) per square inch	16.01846	kilograms per cubic meter
pounds (force) per cubic foot	6894.757	pascals
square feet	0.09290304	square meters
tons (short, mass)	907.1847	kilograms
tons (mass) per acre	0.2241702	kilograms per square meter

---

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SECTION 1

INTRODUCTION

This introduction briefly explains the general tone and direction of this engineering guidance document and its strongest recommendations -- away from phenomenology and toward strict engineering with accountability in value and long-term service.

Regulations for the management of hazardous waste disposal facilities have now been promulgated by the Environmental Protection Agency (EPA) as directed by Congress in the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA). New hazardous waste disposal facilities must meet the requirements of Title 40, Code of Federal Regulations, Part 264 (40 CFR 264) in order to receive a permit. RCRA also dictates actions for correcting old sites presenting endangerment. As a part of its response to RCRA, the EPA has issued technical documents such as this one to assist in the complex and important task of planning technically adequate disposal facilities.

PURPOSE

This document provides technical guidance on design, construction, and maintenance of cover for hazardous waste facilities (Figure 1)[1] based largely on waste management practice, concepts in soil construction, and innovations from research for EPA and others. However, the technical content is organized to encourage new designs and practice developed by creative and competent engineers within the limits of RCRA regulations. Suitable designs are ultimately translated into construction through plans and specifications, and therefore some of the guidance is formulated directly as specifications.

REGULATORY GUIDANCE

EPA has issued basic technical guidance to assist the permit writers and others in regulating the disposal of hazardous waste as intended in RCRA. The guidance document for cover was prepared and distributed in draft form (1)[2] by the Office of Solid Waste. In case of any contradiction or conflict in design, that Office of Solid Waste guidance as well as the underlying statute and regulations take precedence over the engineering guidance in the present

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[1] In the context of 40 CFR 264 this cover guidance is applicable to many surface impoundments (Subpart K) as well as all landfills (Subpart N).

[2] Number in parenthesis stands for citation listed under REFERENCES.

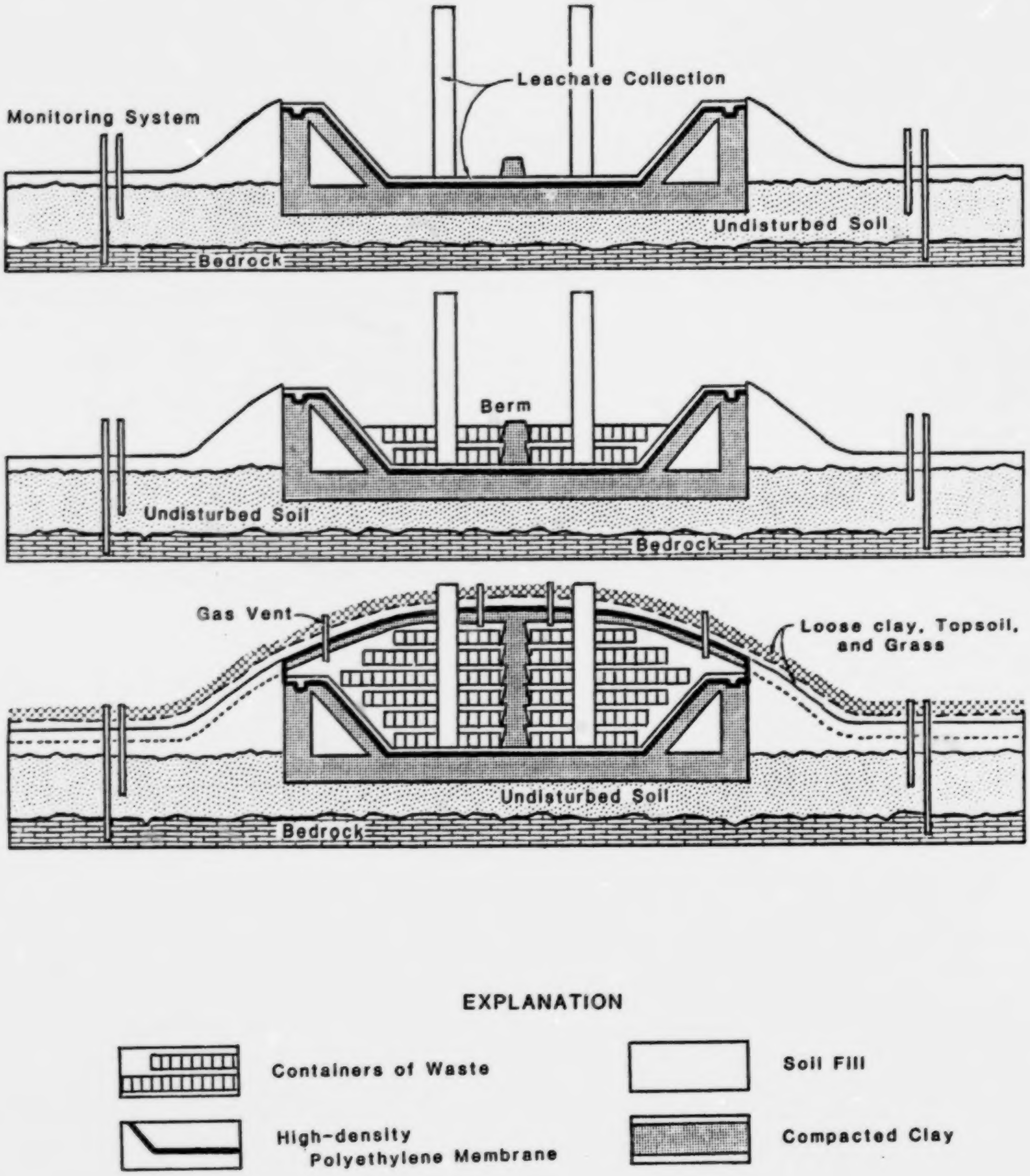
Leachate Collection
Monitoring System
Undisturbed Soil
Bedrock
Berm
Undisturbed Soil
Bedrock
Gas Vent
Loose clay, Topsoil, and Grass
Undisturbed Soil
Bedrock
EXPLANATION
Containers of Waste
Soil Fill
High-density Polyethylene Membrane
Compacted Clay

Figure 1. Covered waste cell at CECOS facility.

document. A minimal cover system for new facilities satisfying these governing RCRA sources is illustrated in Figure 2. It should be expected that thicker and more complex cover systems will often be required.

PREVIOUS ENGINEERING GUIDANCE

Engineering guidance offered in the past on solid waste management has sometimes presented a mixture of descriptive phenomenology or research conclusions in place of straightforward engineering practices, and, some past cover design has been accomplished by other than experienced engineers. Descriptions of processes or results of specific tests are often helpful conceptually but seldom substitute for quantitative solutions and the systematic approach of engineers. Disposal engineering has occasionally been made additionally confusing by the failure to use engineering terminology and other language recognizable as authoritative and workable to those expected to construct the facilities. Solid waste disposal is not a simple technical task, and a versatile, experienced engineering staff is one of the most important ingredients in construction, operation, and closure.

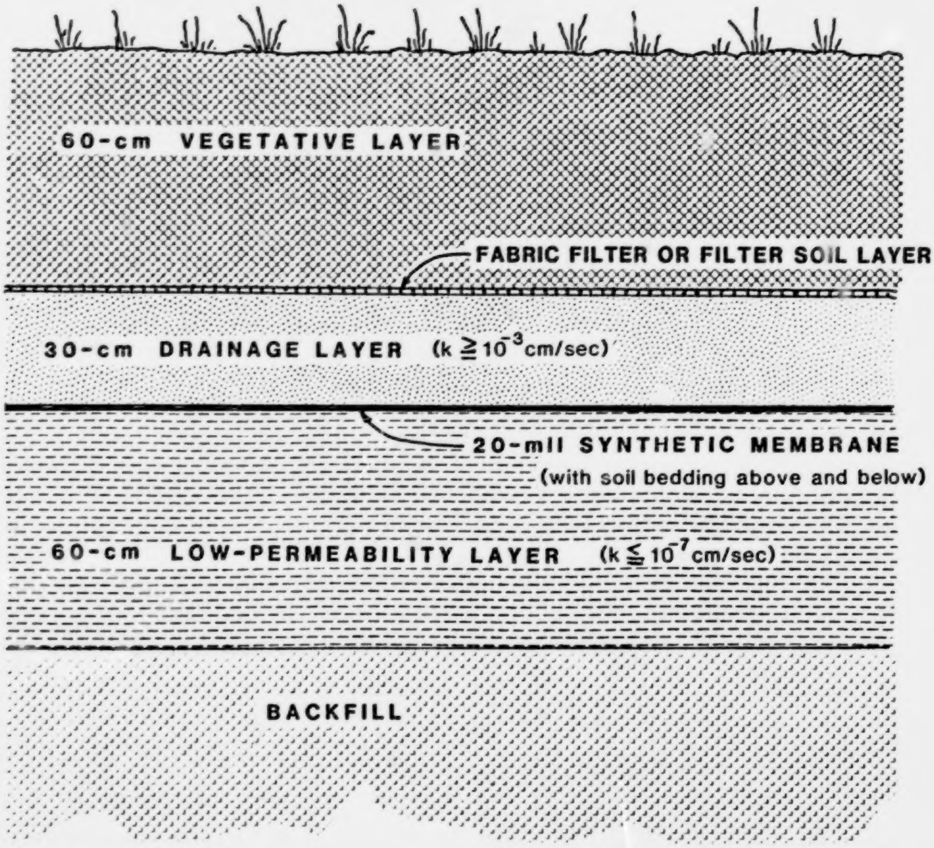
60-cm VEGETATIVE LAYER
FABRIC FILTER OR FILTER SOIL LAYER
30-cm DRAINAGE LAYER (k ≧ 10^{-3} cm/sec)
20-mil SYNTHETIC MEMBRANE
(with soil bedding above and below)
60-cm LOW-PERMEABILITY LAYER (k ≦ 10^{-7} cm/sec)
BACKFILL

Figure 2. Minimal cover components as described in RCRA guidance.

A previous technical resource document and its backup report by Lutton and others (2,3) attempted to discourage shallow conceptual "engineering" by discussing the many interrelated factors impacting on performance of cover systems. It was emphasized that the uniqueness of each site often dictates a unique design. It was also emphasized that an engineer's creative interest is a resource that should be used to the fullest. These criteria continue to be applicable to design, construction, and maintenance of cover systems.

SCOPE OF DOCUMENT

With the advance of research and development, changes in regulatory requirements, and growing experience gained in the operation of previous disposal works, guidance has advanced to a more definitive form from the earlier emphasis on general physical principles and possible mechanisms impacting cover design. Therefore, the present document should be regarded as superseding the two previous documents (2,3) wherever there is an apparent conflict or contradiction. Portions of those previous documents of a qualitative nature and more descriptive of possible processes remain valid in that context, and accordingly those documents are still useful for supplementary guidance.

A primary function of cover at most hazardous waste facilities is to exclude from the waste cells most water percolating downward from the ground surface. Although this function is not always the main concern, e.g. in arid regions, it always ranks high and clearly deserves concentrated attention in the design stage. Analysis of cover designs for impedance of percolation is explained herein and emphasized as a necessary step with possible quantitative feedback in design modifications.

This document also places high priority on realizing long design life for the cover. Natural, near-surface processes will begin to attack the cover immediately after construction since the cover is more or less out of equilibrium with the natural environment. Guidance is provided on designs to minimize erosion and on maintenance practices for what may prove to be the inevitable. Comparable deterioration localized in the subsurface must also be given sufficient forethought and taken care of in the design to avoid a more subtle, but persistent, damaging process.

After a discussion of useful preliminaries in Section 2, the main subjects are covered in three broad parts of the document: design, construction, and maintenance. Sections 3-5 together address design concepts in sufficient detail to encourage the creative engineer to review workable options and integrate them into a suitable design. Section 3 presents design methods; Section 4 addresses cover stratification (in the vertical dimension); and Section 5 presents design factors that must be considered along the horizontal dimensions of the facility.

Cover construction is detailed in Sections 6-8. Section 6 reviews the concepts and methods of soil construction as well as those for membrane and filter fabric installation. Section 7 addresses quality control, quality assurance, and acceptance testing. Section 8 reviews general vegetation practices by drawing heavily from a previous report for details.

Post-construction monitoring and inspection are included in Section 9 and maintenance and repair in Section 10.

Specifications including several for vertical cover designs recognized as effective are presented in Appendices A and B.

USERS OF DOCUMENT

This document is intended to be useful to all technical and nontechnical persons concerned with the construction, operation, and closure of hazardous waste disposal facilities. Users may be allied with the federal or state government, the facility owner, the facility operator, or an independent contractor. The specific viewpoint may be that of a design engineer, the applicant for a permit, a permit reviewer, a construction engineer, or the site manager as well as others with related interests in hazardous waste management. Construction and monitoring inspectors should be among the leading beneficiaries since they can find in the document summaries of good practice in construction and monitoring using the latest concepts and techniques set in the context of the overall operation from planning to post-closure care. Despite the diversity of viewpoint and allegiance, the main parties are linked frequently through a formal contract (Table 1), and their interrelationships one to another deserve clear definition.

TABLE 1. KEY PARTIES IN CONTRACTING FOR CONSTRUCTION OF COVER

Owner	For whom the work is performed; prepares or authorizes plans and specifications and pays for the work
Contractor	Agrees to perform the work according to plans and specifications at established price or price formula
Engineer	Owner's representative formally identified in the contract
Regulator	Outside party exerting influence through regulations and in a review capacity

Notes: The terms Owner, Contractor, and Engineer are frequently capitalized in contracts, emphasizing their specificity and importance.

The Engineer is frequently, but not necessarily, within the Owner's organization.

The user should find the sample specifications and the other guidance presented in the language of construction contracts to be helpful in making quantitative evaluations of existing documents or in preparing new documents.

With maturation of the hazardous waste management industry, the convenience of descriptions and specifications in qualitative or semiquantitative terms has disappeared. Although performance standards are advantageous at higher levels, there is a point in the chain of responsibility for well-engineered construction where prescriptive specifications are essential. This need may arise in regard to portions of the facility, e.g. in directions to a contractor responsible only for satisfactory placement of the cover.

OTHER APPLICATIONS

The guidance is also applicable to other than covering new hazardous waste facilities as follows:

a. Design and construction of cover systems suitable for nonhazardous waste, e.g. municipal waste.

b. Design, construction, and maintenance of cover systems for remediating uncontrolled waste sites as under RCRA or under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

c. General conceptual guidance for expanding or tightening specifications for hazardous waste disposal facility features other than cover, particularly specifications for liner systems, impoundment dikes, and drainage and for waste emplacement.

Expanding on b above, it should be pointed out that a separate report on covering uncontrolled sites has been prepared recently (4). However, it should also be emphasized in engineering for cover systems, that the distinctions between new facilities and uncontrolled old sites are minor at most. Engineering objectives and methods are essentially the same.

LEGALITY

This document in itself does not constitute formal EPA regulatory policy and in no way relieves owners and other parties of their respective responsibilities in construction and in hazardous waste management. The user should be aware that the use of guidance from this document in permits, specifications, and other binding legal documents is not tantamount to approval by any other than the signatories of the legal documents.

SECTION 2

BASIS OF TECHNICAL DESIGN

This section summarizes the considerations that must be carefully reviewed before beginning to design the cover. The factors discussed below will affect the composition, dimensions, and interrelationships of components in the cover system. The first step in the design process, therefore, is to assemble appropriate documentation or prepare a synopsis of each factor and its impact.

SITE CHARACTERIZATION

The physical characteristics of the site and the configuration of its surface are among the most important factors upon which cover design is based. Sometimes the influence of site characteristics on cover design follows a more direct influence on design of the entire disposal unit or the assemblage of disposal units.

Topography

The importance of topography can be brought out by considering two different but typical cases: one site located on flat terrain and another on hilly terrain with an average slope of 5 to 10 percent. It will almost certainly be necessary to limit the size of disposal units or waste cells in the hilly terrain, and their orientation and arrangement may also be restricted by operational considerations. Broad flat sites present fewer restrictions on size, orientation, and arrangement of the disposal units, one to another.

Siting in a canyon or at the head of a hollow is one option favored in some hilly terrains. An engineered embankment across the canyon encloses the lined fill area on the downstream side. Drainage of surface water may converge on a central ditch superimposed on the waste cells generally above the original stream bed. This system contrasts with the usual arrangement of drainage ditches carrying runoff outward to the nearest edge of the fill area.

The constraining influence of topography is illustrated in the extreme at Oak Ridge National Laboratory (Figure 3). Unlined disposal trenches for low-level radioactive waste (LLRW) are arranged to take advantage of relatively flat topography on ridge tops and spurs. The orientations of trenches show a relationship to topography, partly for ease of operations. Even the small size of the trenches has been determined to some extent by topography; trench length was reduced during the evolution of burial practice to reduce seepage from the lower ends of trenches flooded by so-called bathtubbing. Although short, narrow trenches are seldom if ever used in commercial RCRA facilities

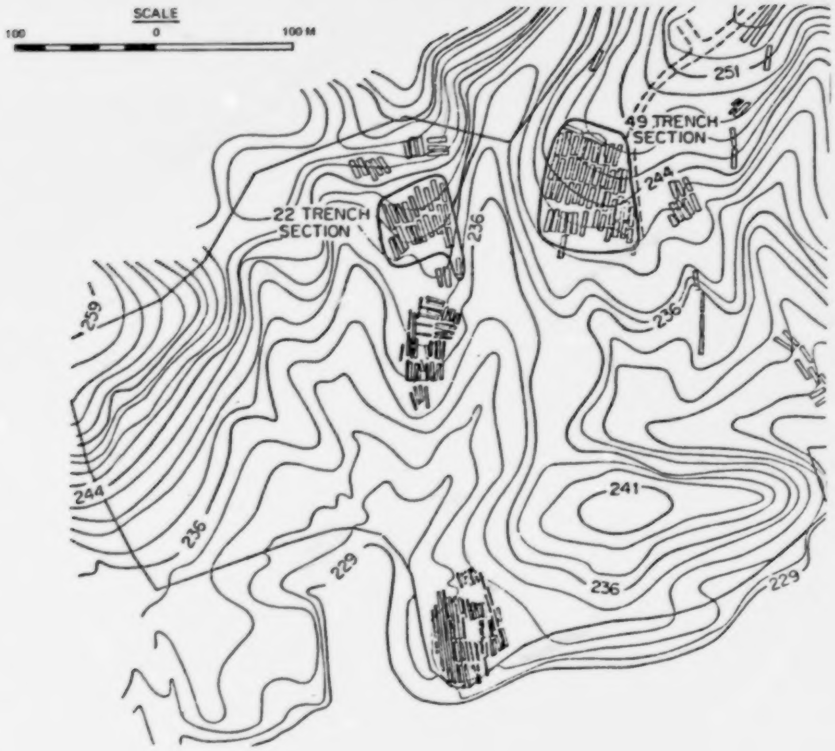

Figure 3. Burial trenches at Oak Ridge area 6.

and the bathtubbing phenomenon is similarly precluded by liners and leachate collectors, a systematic consideration of such factors should suggest useful redundancies in design.

The geomorphological consequences of topography must be considered. Canyon fills may be expected to experience erosion and related effects increased in proportion to the area of the upstream watershed. On mounded landfills that area is less than the fill area itself. Finally, the questions of flooding and floodplains deserve attention. RCRA regulations are briefly explicit in regard to disposal and disposal practices there (40 CFR 264.18). Normal flow and storage must remain unobstructed and there must be no erosion of the landfill.

Geological Media

Geologic media have rather subordinate status in disposal of hazardous waste according to 40 CFR 264 because of the usual requirement of a liner below and around the waste. However, media of low hydraulic conductivity can provide capacity for retarding migration of some pollutants in ground water, and thus an extra measure of protection in case of unexpected leakage or malfunction. Disposal sites are often selected at least partly on this basis. Obviously, the best sites are those capable of transmitting ground water only slowly if at all. A rate of 1 ft/year has been suggested as a sufficiently conservative upper limit. In contrast, any waste disposal unit situated in a pervious setting, such as a gravel pit, over an unconfined aquifer would ordinarily deserve very conservative cover and liner designs with redundancies and other special features for an extra factor of safety.

Geological media may also have importance to the extent that on-site soils are used to construct the cover and its supporting backfill or temporary cover. Presumably some sites will be chosen partly on the basis of the availability of sufficient soil for backfilling and cover construction. Once this strategy is adopted, the physical characteristics and quantities of the soils available at the site may serve to constrain the cover design to some extent.

In-place density and condition of soil as well as its availability can be important in satisfying soil volume requirements. Experienced engineers (5) have suggested that most soils have natural densities short by 10 to 30 percent of the soil's maximum density by standard compaction tests (See Test Criteria, SECTION 6). Since that maximum density is the target of good construction compaction, it may frequently be that required volumes will have to be adjusted upward to compensate for the shortfall resulting from compaction. It should be mentioned, however, that experience (2) also suggests that some overconsolidated geological strata exhibit the opposite behavior, i.e., a swelling upon excavation and compaction in a cover system.

WASTE CHARACTERIZATION

The character of the waste can have long-term impacts on the cover and its performance in regard to problems of subsidence, differential offset, and soil particle migration. It is even helpful conceptually to regard the disposal unit as the lower component or foundation of the cover with a transition to the backfill soil within the waste cells. Influences follow either from the voids and other physical condition of the waste at the time of burial or from chemical-related changes that take place over a long period. It is important to characterize the waste to focus attention on unfavorable eventualities that in some cases may actually be avoidable. It would be advantageous to evaluate the character of the waste before the waste is emplaced. Certain worthwhile limitations on waste character and form as well as placement procedures may be suggested and then incorporated in the plan of operations.

Voids Within Containers

The approximate void space within disposal packages or containers should be estimated carefully for various categories of waste anticipated. It will also be possible to make at least a rough estimate of the participation of these void spaces in long-term general settlement. Void space left at the top of a sealed steel drum will presumably remain inaccessible to processes of deterioration until the steel drum has begun to break down through corrosion. Similarly, it can be expected that the small voids dispersed through compacted and baled waste[1] will remain inactive and largely inaccessible to processes of deterioration for many years. Small evenly dispersed voids in absorptive waste may serve to draw in and retain moisture over a long period and undergo very little other physical change. Prediction of subtle changes that may be taking place 50 or more years in the future will be accompanied by considerable uncertainty but nevertheless deserves serious consideration and probably will be useful.

Voids Among Containers

In comparison to void space within containers, the void space between or among containers in the disposal unit is easier to describe and more directly relatable to cover deterioration. Four aspects of space among containers are clearly important and need description: total volume, approximate continuity, portion occupied by backfill soil, and distribution of backfill soil.

The importance of total space among containers can be brought into focus by considering first the contrast in volume between extreme categories such as barrels disposed randomly and boxes or bales stacked in closely packed, orderly array (Figures 4 and 5). The comparison is pertinent to the extent that cylindrical barrels and rectangular packages are common container forms. However, it should be emphasized that space-wasteful random disposal is usually avoided at cost-conscious commercial disposal facilities. Space among barrels dumped more or less randomly would approach 40 percent of total volume in the disposal unit. Space among uniform boxes carefully stacked in a rectangular pattern ordinarily constitutes less than 5 percent of total volume. However, even here a few percent of such space, when concentrated in its distribution, may eventually affect the cover integrity.

The distribution and linkage of space among containers becomes important in the arrangements with the least volume between containers, e.g. the stacked box array. Chains of voids between boxes may project downward from the cover through two or more layers of boxes and may present a serious threat of cover disruption, primarily because they can be overlooked until the damage is underway. Piping (migration) of backfill soil originally occupying these voids eventually undermines the cover and can cause disruption.

Where open space is relatively high, e.g. among disorderly arranged barrels, long pathways for piping are numerous, and the potential for cover deterioration should be obvious. Clearly, a disordered array of barrels may persist as a threat of cover deterioration for many years. Figure 4 shows a nonsystematic accumulation of barrels at one old LLRW facility. The long-term threat of settlement is circumvented by use of dry sand backfill which fills voids better at the start.

Obviously one way of reducing the long-term threat to cover by piping along voids in the waste is by the careful backfilling of the voids with soil. In characterizing the waste, it is necessary to estimate the percentage of space actually filled with backfill soil. Where the percentage is

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[1] Baled waste may be considered as contained by the bale straps.

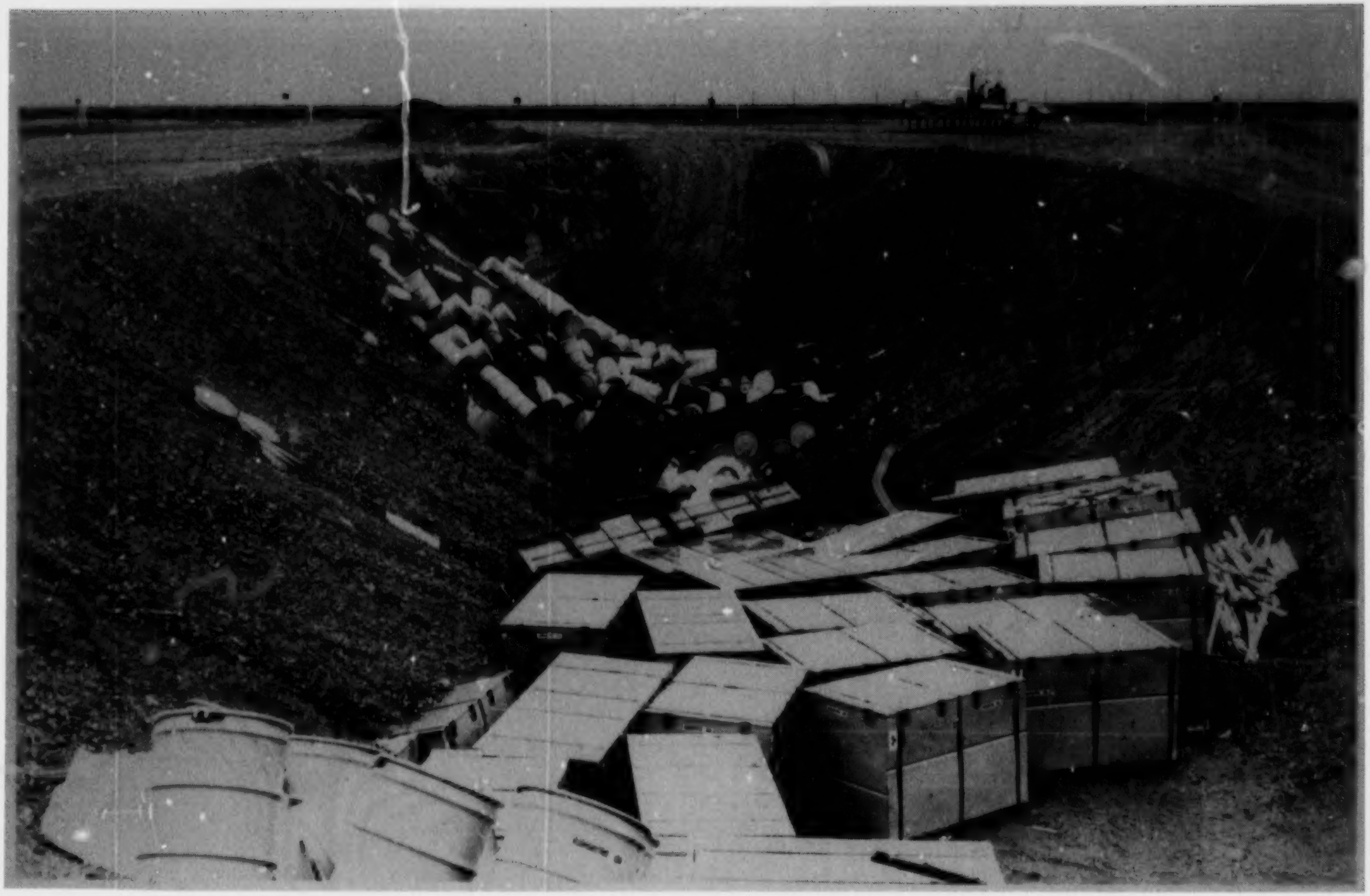


Figure 4. Nonsystematic disposal of waste at Beatty LLRW facility (atypical practice).

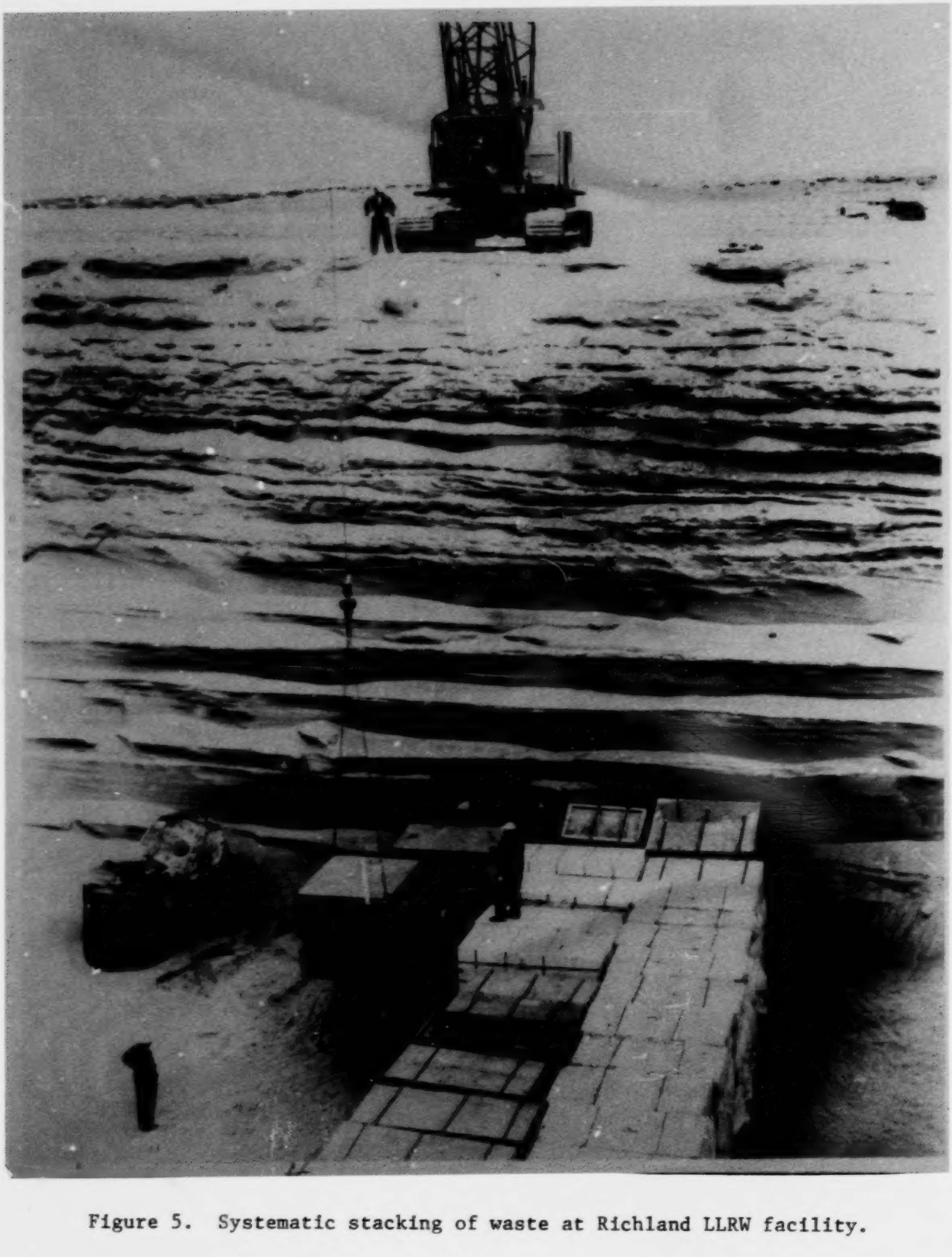


Figure 5. Systematic stacking of waste at Richland LLRW facility.

substantially less than 100 percent, it is also helpful to describe the distribution of the backfill. Such a description or characterization should be useful in specification of the backfilling procedure or the result to be obtained, i.e., by prescriptive or performance specification, respectively.

Chemical Constitution

The chemical constitution and the reactivity of bulk and containerized waste always deserve careful consideration. A listing of wastes to go into each cell is already required in Subpart B, 40 CFR 270. In large disposal facilities, this undertaking may be complicated or simplified by any operational plan to segregate wastes into subcells according to waste type. The eventual deterioration and breakdown of initially rigid elements such as steel barrels, bale straps, and boxes will have to be evaluated as to their expected histories and the ultimate effects. Although it is frequently found that metals and sometimes even paper are little affected by burial in the short term (e.g. at the Savannah River Plant), the long-term effects over tens of years and to the design life of the facility must be addressed to the highest degree available with state-of-the-art knowledge and practice.

The potential for generation of gases or liberation of volatiles should also be considered. It may be necessary to provide diversions and vents for gases blocked from their upward pathways by the cover. Vents to the atmosphere may be adequate for toxic components of low concentration that will be quickly dispersed in the air to acceptable levels. In extreme cases where the gas or volatile component may reach a harmful concentration, it may be necessary to provide on line or contingency features for absorption filters or other means of reducing concentration of toxic components. General categories of reactive wastes that can conceivably affect the performance of cover are provided in Table 2.

TABLE 2. WASTES WITH POTENTIAL FOR AFFECTING COVER

Volatile organic chemicals
Inorganic acids
Materials capable of reacting with others in the waste cell*
Materials capable of undergoing volume change
Saturated materials

*See lists of potentially reactive wastes in Appendix V of 40 CFR 264.

DESIGN LIFE

Certainly one of the most important considerations impacting on cover design and construction is the design life or service life of the facility.

By this we mean how long the waste is expected to remain secure--not the shorter period of active operation. The cover situated at the ground surface is exposed and subjected to complex near-surface conditions and processes. Where the effectiveness of the cover system is required over hundreds of years by a long design life for the facility, the system is subjected to an unusual demand not found in most other types of construction. Table 3 contrasts the design life for several waste facilities with shorter design lives in the more usual types of construction such as for highways and dams. Such a design life has not been defined for RCRA facilities. Without sufficient care in estimation, the ultimate cost of a facility may greatly exceed estimates at the time of construction as maintenance and repair costs accumulate.

TABLE 3. DESIGN LIFE FOR VARIOUS STRUCTURES AND FACILITIES

Facility or Feature	Expected Service Life (yrs)	Specifics and Remarks
Railroad subgrade (repairs)	40	Repairs against pumping of soil (6)
Soil retaining structure (with fabric)	50	Reference 7
Roads	20	Reference 8
English Channel tunnel (future)	>120	Suggestion of Anglo-French Working Group
Intermediate-level radioactive waste storage	20	Temporary
Uranium mill tailings control	1,000	40 CFR 192
High-level radioactive waste disposal	10,000	EPA standard of 1985
Low-level radioactive waste burial facility	500	--
Fly ash disposal area	1000	Scientific scenario (9) rather than conservative engineering analysis

The dramatic impact of long design life can be brought into sharper focus by considering previous experience with the expectable life for similar engineered features. Table 4 summarizes experience with various types of lining for irrigation canals, an engineered feature having requirements of low permeability and erosion resistance similar to those of cover systems. Even with these relatively short service lives frequent maintenance is required.

TABLE 4. DURABILITY OF CANAL LININGS*

Lining Type	Service Life (yrs)	Remarks
Cement concrete	50	Some to 60 years
Cement-brick	20	Annual maintenance
Buried concrete pipe	50	Low maintenance
Soil-cement	--	Some to 23 years
Asphalt-clay plaster	5	10 percent/ann. maintenance
Mud plaster	2	25 percent/ann. maintenance
Exposed membrane (thin)	2**	Temporary
Compacted soil (in situ)	--	Repeat compaction annually
Asphaltic concrete	20	--
Compacted earth	20	Susceptible to weather effects

*Data from Reference 10.

**Recent experience indicates that life of exposed resistant membrane material can exceed 25 years.

Certain strategies may be adopted to reduce the long-term cost and necessity for continuing maintenance. Where pertinent factors are carefully summarized and evaluated as a preliminary to design of cover, this analysis may lead to modifications of design at the planning stage that can be incorporated into specifications not only for the cover but also for other parts of the disposal facility as well. An example of one strategy is to target vegetation plans on native species of grass that will be most hardy in the environment and conditions characteristic of the site. This strategy is based on the assumption that hardy, native species will be more likely to succeed and persist with minimum care and maintenance.

Consideration of design life logically leads to consideration of storing hazardous waste. RCRA regulations are already in place as Subparts K and L of 40 CFR 264 to address impoundments and waste piles as approved methods of storage. Neither type of storage area requires a cover except as might be needed to prevent wind dispersal, and accumulation of waste usually continues.

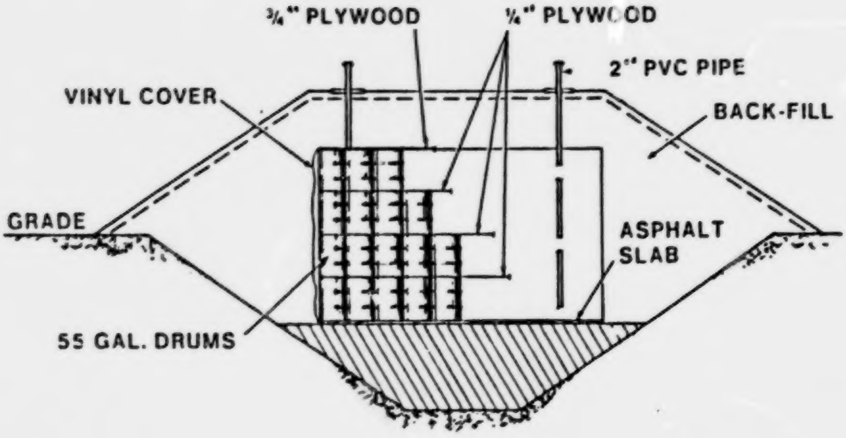


Figure 6. Storage facility for radioactive waste at Hanford reservation (11).

An acceptable impoundment may be converted from storage to permanent landfill by appropriate stabilization and solidification of the waste and installation of final cover. A waste pile can be closed as a permanent landfill only provided that it meets all requirements of Subpart N for landfills.

Outside of RCRA, the experience with engineered storage facilities has been confined largely to radioactive waste. Figure 6 illustrates one such storage unit. The waste is stacked on an asphalt pad, then covered with a synthetic membrane and buried with a thick soil cover. A minimum of 20 years is specified in which the waste packages can be retrieved for permanent disposal elsewhere. Of some, though not overwhelming, importance is the fact that part of the most threatening radioactivity of short-lived isotopes will have decayed during this storage period.

OPERATIONAL PLAN

The operational plan for a disposal facility can be expected to affect cover construction and even cover design to some extent. Procedures will have been established on the basis of previous experience or in accordance with regulations and local requirements. For example, it may have been previously established that the facility will consist of trenches of given depth (Table 5). Certain combinations of equipment may be favored by a contractor so that the disposal operation is heavily influenced in turn. The anticipated volume of waste and the anticipated rate at which that waste reaches the site will certainly have major impacts on operational plans. It is sometimes advantageous to fill disposal units on a yearly basis so that the best season of the year can be used for closing and covering the disposal unit and establishing a vegetated cover. Ongoing operations will determine to some extent the placement of cover in increments or at one time.

TABLE 5. SOME TYPES OF DISPOSAL OPERATIONS

Method	Typical Dimensions (m)	Remarks
Narrow trench	3 x 3 x 40	Seldom used
Wide trench	7 x 30 x 150	Common
Mound	3 x 30 x 150	Seldom used
Simple areal fill	7 x 150 x 150	Common
Layered areal fill	20 x 150 x 150	Common
Composite*	--	Common

*Methods are commonly combined where site topography is complex or where flat terrain permits great lateral extension.

A major distinction among operations is made between waste disposal in multiple lifts and disposal in a single lift (Figure 7); similarly for large areal fills versus disposal in trenches (Figure 8). Disposal in narrow trenches is commonly accomplished in one lift thickness, in which case the covering can be started in sections as the trench is filled from one end to the other. Many large areal fills rising above original ground surface are completed in more than one lift, so that it is impossible to place the final cover until the entire disposal unit is largely filled. Even then, however, it may be possible to delineate portions of the fill area as separate disposal units.

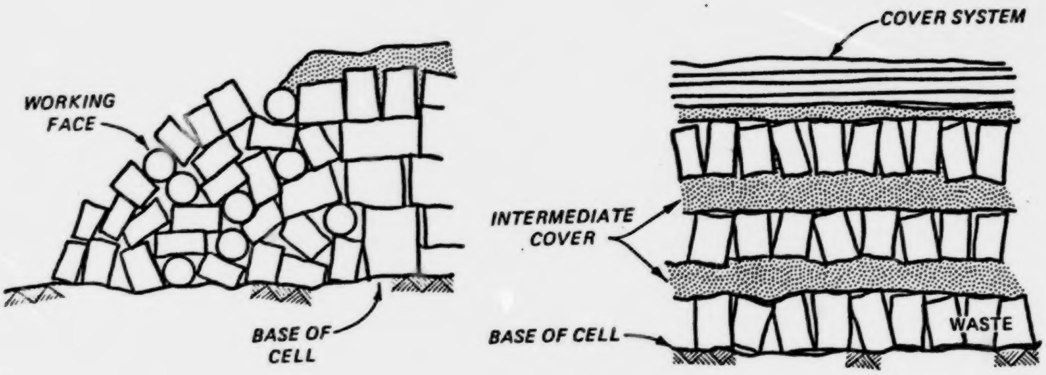
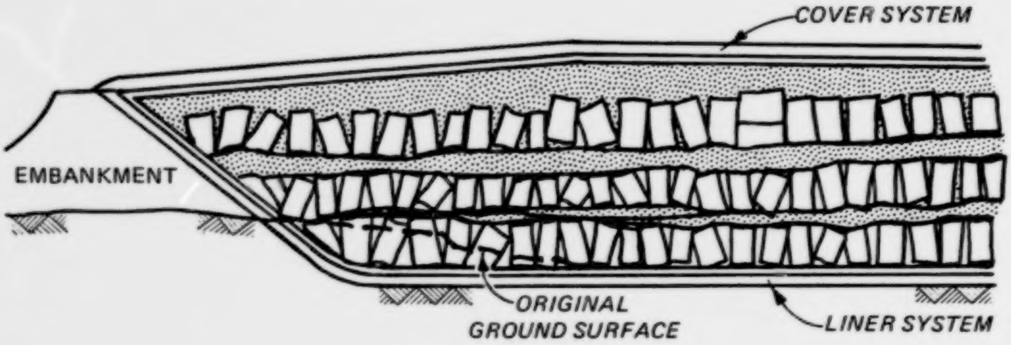
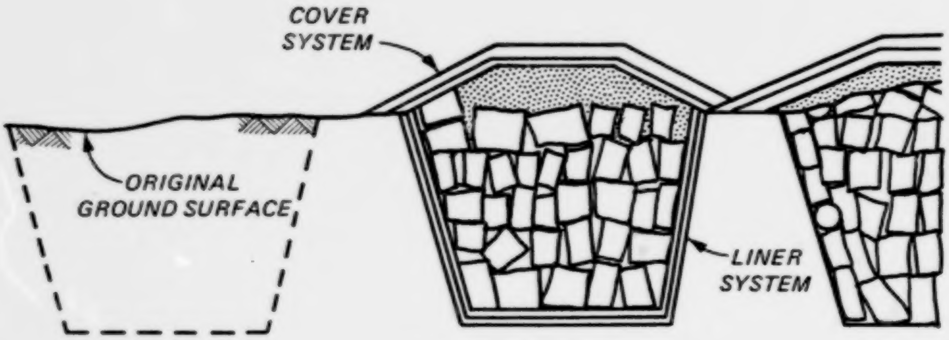


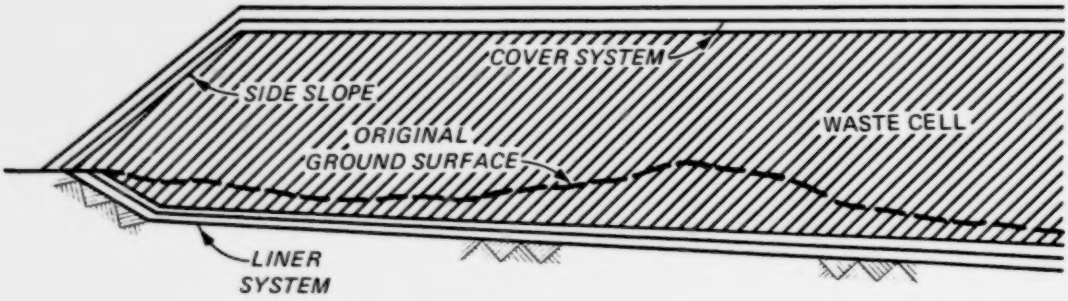
Figure 7. Waste emplaced in single and multiple lifts.


COVER SYSTEM
EMBANKMENT
ORIGINAL GROUND SURFACE
LINER SYSTEM

CONFINED UNIT
(ALSO SEE FIGURE 1)


COVER SYSTEM
ORIGINAL GROUND SURFACE
LINER SYSTEM

TRENCH CELL


COVER SYSTEM
SIDE SLOPE
ORIGINAL GROUND SURFACE
WASTE CELL
LINER SYSTEM

AREAL LANDFILL

Figure 8. Waste emplaced above and below original ground surface.

Many commercial RCRA facilities fill in lifts across large areas and rise lift by lift from a base below original ground to a final level well above original ground. This popular plan has evolved as the most cost effective and is used even in canyon-fill and head-of-hollow operations. Intermediate cover (Figure 7) sometimes includes bulk waste compacted like or with soil.

HYDROLOGY

The hydrological system constitutes the most influential combination of related external factors in cover design and maintenance. Figure 9 shows the hydrological system in its broadest sense and Figure 10 in the more restricted sense where attention is concentrated on cover performance. The several aspects of climate, particularly the precipitation regime, have direct impacts on the performance of the cover in blocking percolation into the waste cell. Besides being foremost among general constraints to cover design, the climate enters into detailed analysis and evaluation of proposed cover designs as explained in Section 3. The importance of the hydrological system can be illustrated by considering two extreme cases.

It is believed that most of the low rainfall of a typical year at the arid Hanford and Richland, Washington LLRW disposal facilities penetrates no more than a few meters of depth. Since the ground water is at much greater depth, most radionuclides carried downward by percolating water stop well above the water table (Figure 11). Thus, these facilities and another hazardous waste facility to the south near Arlington, Oregon benefit directly from the dry regime. On the other hand, uncontrolled waste sites in the relatively damp midwestern and eastern United States frequently exhibit ground-water contamination plumes of serious dimensions and concentrations despite the presence of cover over the waste in some cases. Major storm events must also be considered since even an arid region can be subjected to infrequent but major storms that cause anomalous ground saturation and percolation to depths ordinarily not reached. Accordingly, a rather complete review of expectable storm events and their frequencies should be required in preparing the background on the hydrological system.

Other aspects of the hydrological system that need to be reviewed are the evapotranspiration history, the water-retention characteristics of the near-surface soil, and surface runoff parameters as well as available measurements at gaging stations. In the broader sense of hydrology (Figure 9) the ground-water system constitutes an important part. Characteristics of the ground-water system are summarized in Table 6. Familiarization with ground-water configuration, flow directions, and velocities is essential, if for no other reason than for background to planning and contingencies for unexpected performance or even failure of the containment system.

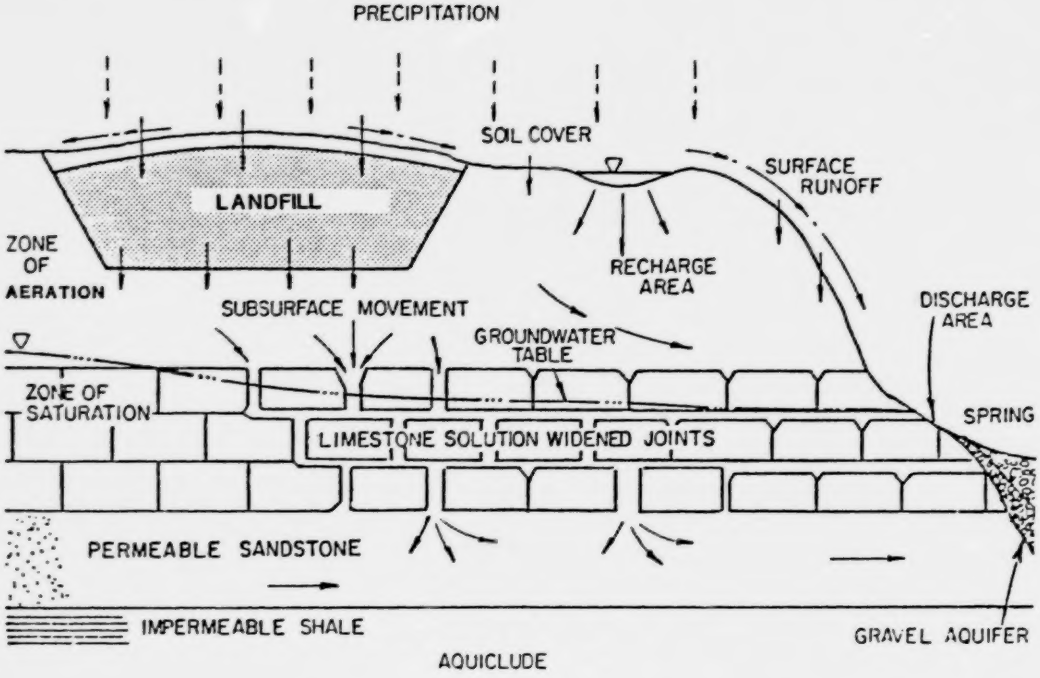

PRECIPITATION
SOIL COVER
SURFACE RUNOFF
LANDFILL
ZONE OF AERATION
RECHARGE AREA
SUBSURFACE MOVEMENT
DISCHARGE AREA
GROUNDWATER TABLE
ZONE OF SATURATION
SPRING
LIMESTONE SOLUTION WIDENED JOINTS
PERMEABLE SANDSTONE
IMPERMEABLE SHALE
GRAVEL AQUIFER
AQUICLUDE

Figure 9. General hydrological system.

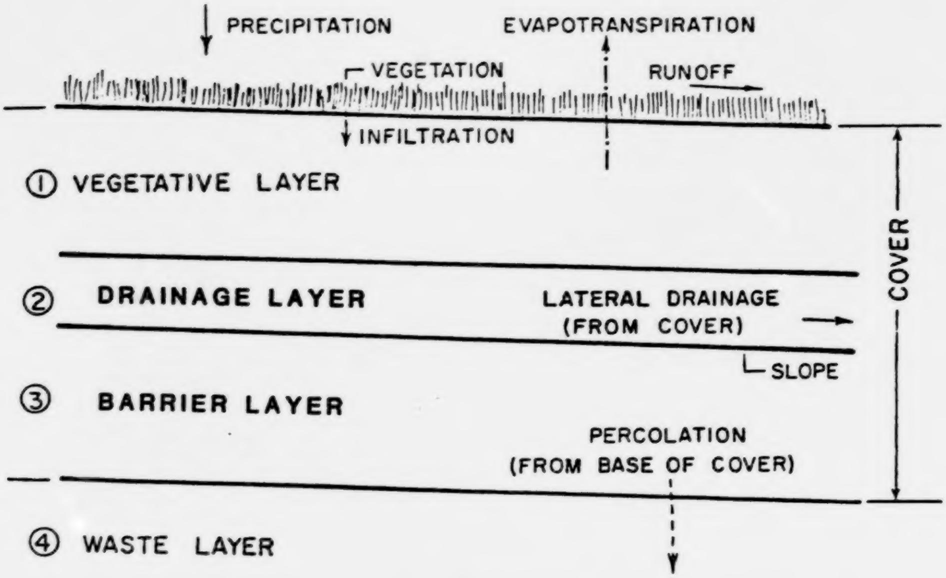

PRECIPITATION
EVAPOTRANSPIRATION
VEGETATION
RUNOFF
INFILTRATION
① VEGETATIVE LAYER
② DRAINAGE LAYER
LATERAL DRAINAGE (FROM COVER)
SLOPE
③ BARRIER LAYER
PERCOLATION (FROM BASE OF COVER)
④ WASTE LAYER
COVER

Figure 10. Hydrological system impacting on cover design.

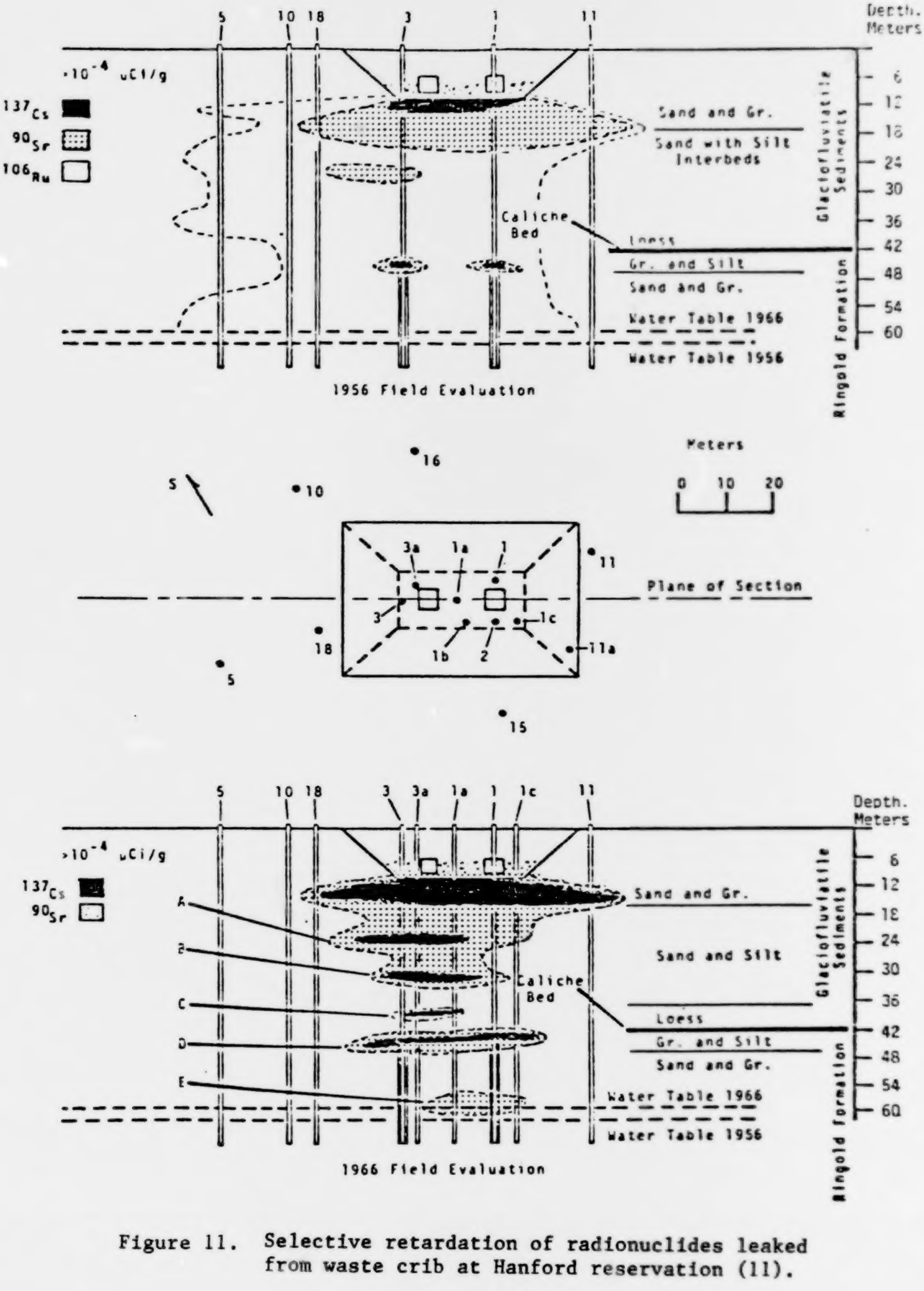

Depth, Meters
>10⁻⁴ μCi/g
¹³⁷Cs
⁹⁰Sr
¹⁰⁶Ru
Sand and Gr.
Sand with Silt Interbeds
Caliche Bed
Loess
Gr. and Silt
Sand and Gr.
Water Table 1966
Water Table 1956
Glaciofluviatile Sediments
Ringold Formation
1956 Field Evaluation
Meters
0 10 20
Plane of Section
3a
1a
1
1b
2
1c
11a
16
10
11
18
5
15
A
B
C
D
E
Sand and Silt
1966 Field Evaluation
6
12
18
24
30
36
42
48
54
60

Figure 11. Selective retardation of radionuclides leaked from waste crib at Hanford reservation (11).

TABLE 6. GROUND-WATER PARAMETERS IMPORTANT AT DISPOSAL FACILITIES (12)

General ground-water system and boundaries
Recharge and discharge areas
Water zone boundaries
Hydraulic conductivities
Heads, potentials, or pressures
Seepage velocity or apparent velocity
Flow direction
Water-holding parameters
Ground-water chemistry

SECTION 3

DESIGN METHODS

This section is purposely restrained in its discussion of rigorous design methods since guidance on design of cover should be left sufficiently open to benefit from the skill of the design engineer. Certain aspects of design are emphasized however as usually necessary in the formulation of suitable plans and specifications. Table 7 presents some of the factors influencing broad design concepts and practice of adequate thickness and effective layering.

TABLE 7. FACTORS IN DESIGN OF COVER SYSTEMS (11)

General site characteristics	Daily evapotranspiration
General waste characteristics	Thickness of waste
Operational plan	Cell size
General geological setting	Rate of disposal
Design life	Intermediate cover distribution
General hydrology and meteorology	Anticipated settlement
Regulations	Anticipated erosion
Availability of cover materials	Anticipated soil change (weathering)
Population distribution	Bottom liner system
Water supply	Leachate collection features
Daily precipitation	Absorptive capacity of formations

REGULATIONS AND STANDARDS

Designing a cover for hazardous waste logically starts with the applicable regulations or standards and regulatory guidance (1). These requirements not only indicate much about the expected performance but also sometimes prescribe specific technicalities that are regarded through experience as being appropriate (Figure 2). Thus, a soil component of the barrier element of the cover may be required to have a coefficient of permeability $k = 10^{-7}$ centimeters/second or less as measured in the laboratory. A technical challenge comes in both design and construction to ensure that this requirement is met and maintained, especially in view of the common disparity between permeabilities at laboratory versus field scales. Summaries from 40 CFR 264 are given in Table 8 for technical standards and requirements for covers at new RCRA facilities. Regulations are also available for covering existing facilities and uncontrolled sites.

GENERAL DESIGN CONCEPTS

Once the functions of the cover have been established or constrained by regulation or standard or by clearcut technical objectives such as reduction of percolation to insignificant levels, the various aspects and elements of the design are defined and integrated using conventional design methods.

Materials Selection

A key task of cover design is the selection of suitable materials. The cover usually will include a synthetic membrane and large volume of soil or soil-like material, but other materials are sometimes included also: Portland cement concrete, bituminous concrete, seal coats, and geotextiles. Considerable flexibility is available in choice of materials beyond the requirements spelled out in regulations and standards. Guidance on suitability of various types of soil for performing cover functions and for general long-term service has been reviewed elsewhere and is summarized in Table 9. The ranking of soils for various engineering functions is a technique that has also been developed on the basis of considerable experience in the Bureau of Reclamation, Corps of Engineers, and other construction and engineering organizations. Classification is according to the Unified Soil Classification System (USCS).

Emphasis on the best soil for the cover will occasionally be unfeasible since the soils available at or near the site will be the chosen material for reasons of economy. The strategy of cover design then targets on the most effective use of those available materials, usually in a layered construction. The availability of material may extend off-site, sometimes including sources of surplus material otherwise classified as waste. Fly ash available in the near vicinity continues to be an attractive possibility for use. Fly ash has a relatively fine grain size and, by careful compaction or addition of reactive chemicals, can be brought to a strength and permeability that may be suitable for fulfilling cover functions. Other substitutes for native soil are discussed elsewhere (2).

Selection of soil and soil-like materials is based partly on the content of various grain-size components. In designing and in procurement for construction, particular attention is needed to define the grain-size classes unequivocally and avoid misunderstanding and difficulties in obtaining desired results. The grain-size classes can be defined quantitatively by reference to standards such as the American Association of State Highway and Transportation Officials (AASHTO) designations for grout sand and cement sand (13). Grain size can be defined more loosely using terms such as "sand," "granular," and "clayey," but such generalizations are preferably avoided. The sample specification for topsoil in Appendix A gives the size ranges and weight

TABLE 8. TECHNICAL REQUIREMENTS FROM 40 CFR 264*

Paragraph	Requirements
264.15	Follow a written schedule of inspection for problems during disposal operations and maintain a written record (this requirement overlaps timewise on some aspects of closure cover emplacement and should be applied to the extent that it does). Problems to be remedied expeditiously.
264.111	Cover so as to minimize need for further maintenance and to control, minimize, or eliminate escape of hazardous constituent, leachate, etc.
264.112	Written closure plan to be submitted with application for permit.
264.113	Close within 90 or 180 days after receiving final waste volume.
264.115	Independent certification of closure in accordance with specifications.
264.118	Written plan of post-closure care, normally for 30 years, to include monitoring, reporting, and maintenance.
264.142	Up-to-date written estimate of cost of closure.
264.144	Up-to-date written estimate of cost of post-closure monitoring and maintenance.
264.301	Systems for controlling run-on and run-off equivalent to 1-day, 25-year storm.
264.303	Inspection during and after construction of synthetic- or soil-based cover for uniformity, damage, and imperfections (e.g., holes, cracks, thin spots, or foreign matter). Inspection of surface drainage system.
264.310	Cover finally to minimize migration of liquids, to function with minimum maintenance, to promote drainage and minimize erosion and abrasion, to accommodate settling and subsidence without losing integrity, and to have permeability no greater than the bottom liner or natural subsoils. Maintain the integrity and effectiveness of the final cover, including the making of repairs.

*Similar technical requirements can be listed from CERCLA regulations.

TABLE 9. RANKING OF USCS TYPES ACCORDING TO PERFORMANCE OF COVER FUNCTIONS

USCS Symbol	Typical Soils	Trafficability			Water Percolation		Gas Migration	
		Go-No Go (RCI Value)*	Stickiness (Clay, %)	Slipperiness (Sand-Gravel, %)	Impede (k, cm/s)*	Assist (k, cm/s)*	Impede (H_c, cm)*	Assist (H_c, cm)*
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	X (10^{-2})	III	X (6)	I
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	XII (10^{-1})	I	IX ---	II
GM	Silty gravels, gravel-sand-silt mixtures	III (177)	III (0-20)	III (60-95)	VII (5×10^{-4})	VI	VII (68)	IV
GC	Clayey gravels, gravel-sand-clay mixtures	V (150)	VI (10-50)	V (50-90)	V (10^{-4})	VIII Same k values as for Impede Water Percolation	IV ---	VII
SW	Well-graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	IX (10^{-3})	IV	VIII (60)	III Same H_c values as for Impede Gas Migration
SP	Poorly graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	XI (5×10^{-2})	II	VII ---	IV
SM	Silty sands, sand-silt mixtures	II (179)	IV (0-20)	IV (60-95)	VIII (10^{-3})	V	VI (112)	V
SC	Clayey sands, sand-clay mixtures	IV (157)	VII (10-50)	VI (50-90)	VI (2×10^{-4})	VII	V ---	VI
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	IX (104)	V (0-20)	VII (0-60)	IV (10^{-5})	IX	III (180)	VIII
CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	VII (111)	VIII (10-50)	VIII (0-55)	II (3×10^{-8})	XI	II (180)	IX
OL	Organic silts and organic silty clays of low plasticity	X (64)	V (0-20)	VII (0-60)	---	---	---	---
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	VIII (107)	IX (50-100)	IX (0-50)	III (10^{-7})	X	---	---
CH	Inorganic clays of high plasticity, fat clays	VI (145)	X (50-100)	X (0-50)	I (10^{-9})	XII	I (200-400+)	X
OH	Organic clays of medium to high plasticity, organic silts	XI (62)	---	---	---	---	---	---
Pt	Peat and other highly organic soils	XII (46)	---	---	---	---	---	---

(continued)

TABLE 9. (continued)

USCS Symbol	Fire Resistance	Erosion Control		Dust Control	Reduce Freeze Action		Crack Resistance (Expansion, %)
		Water (K-Factor)*	Wind (Sand-Gravel, %)		Fast Freeze (H_c, cm)*	Saturation (Heave, mm/day)	
GW	Same as Impede Gas Migration	I (< .05)	I (95-100)	Same ranking and values as for Wind Erosion Control	X	I (0.1-3)	I (0)
GP		I ---	I (95-100)		IX	I (0.1-3)	I (0)
GM		IV ---	III (60-95)		VII	IV (0.4-4)	III ---
GC		III ---	V (50-90)		IV	VII (1-8)	V ---
SW		II (.05)	II (95-100)		VIII	II (0.2-2)	I (0)
SP		II ---	II (95-100)		VII	II (0.2-2)	I (0)
SM		VI (.12-.27)	IV (60-95)		VI	V (0.2-7)	II ---
SC		VII (.14-.27)	VI (50-90)		V	VI (1-7)	IV ---
ML		XIII (.60)	VII (0-60)		III	X (2-27)	VI ---
CL		XII (.28-.48)	VIII (0-55)		II	VIII (1-6)	VIII (1-10)
OL		XI (.21-.29)	VII (0-60)		---	VIII ---	VII ---
MH		X (.25)	IX (0-50)		---	IX ---	IX ---
CH		IX (.13-.29)	X (0-50)		I	III (0.8)	X (>10)
OH		VIII ---	---		---	---	IX ---
Pt		V (.13)	---		---	---	---

(continued)

TABLE 9. (continued)

USCS Symbol	Side Slope			Discourage Burrowing	Impede Vector Emergence	Discourage Birds	Support Vegetation	Future Use	
	Stability	Seepage	Drainage					Natural	Foundation
GW	Determine on basis of laboratory testing	Same ranking and values as for Impede Water Percolation	Same ranking and values as for Assist Water Percolation	Same ranking and values as for Slipperiness Trafficability	X	All soils are suitable	X	Same ranking as for Support Vegetation	Same ranking and values as for Go-No Go Trafficability
GP					X		X		
GM					VIII		VI		
GC					V		V		
SW					IX		IX		
SP					IX		IX		
SM					VII		II		
SC					IV		I		
ML					VI		III		
CL					III		VII		
OL					VI		IV		
MH					II		IV		
CH					I		VIII		
OH					---		VIII		
Pt					---		III		

* RCI is rating cone index, k is coefficient of permeability, H_c is capillary head, and K-Factor is the soil erodibility factor.

The ratings I to XIII are for best through poorest in performing the specified cover function.

percentages for sand, silt, and clay as used in classification. A better option sometimes is to relate to a recognized size classification system (2).

Table 10 lists some materials other than soil which may also be considered for use in cover systems. Most have been discussed previously (2). Note again that several of these materials are wastes and under certain circumstances have been regarded as potentially hazardous. Even the few questionable materials present much less risk in the context of use in a cover system as compared to their massive disposal elsewhere as the principal waste. Nevertheless, a prior showing of safety is usually required unless all risk is circumvented by using the waste as barrier or foundation below and effectively enclosed by the synthetic membrane (Figure 2).

TABLE 10. SOME LOW-COST SUBSTITUTE MATERIALS FOR COVER

Materials*	Remarks
Fly ash	Alone or blended
Bottom ash	-
Slag	In place of gravel
Mine waste and tailings	Large variety
Incinerator residue	-
Processing plant sludge	High water content
Dredged material	Soil
Sewage sludge	Composted preferred
Foundry sand	May contain tar residue
Manufactured sand	Crushed stone byproduct (14)
Demolition debris	For riprap

*Use of waste material depends on a cost advantage.

Layering

A second opportunity for design creativity comes in the arranging of layers to combine effects beneficially. Layering is perhaps the most promising yet underutilized technique for designing cover systems. By combining two or three distinct materials in layers, the designer may mobilize favorable characteristics of each together at little extra expense. The actual designing using soils available at specific sites will test the ingenuity of the engineer but again the effort deserves strong emphasis. Figure 12 schematically illustrates the layered system. Figure 13 compares a waste cover system to a highway pavement structure -- an analogy whose value is manifested in Appendix A on preparing specifications.

A few of the specific layer combinations that can be developed in layered designs are:

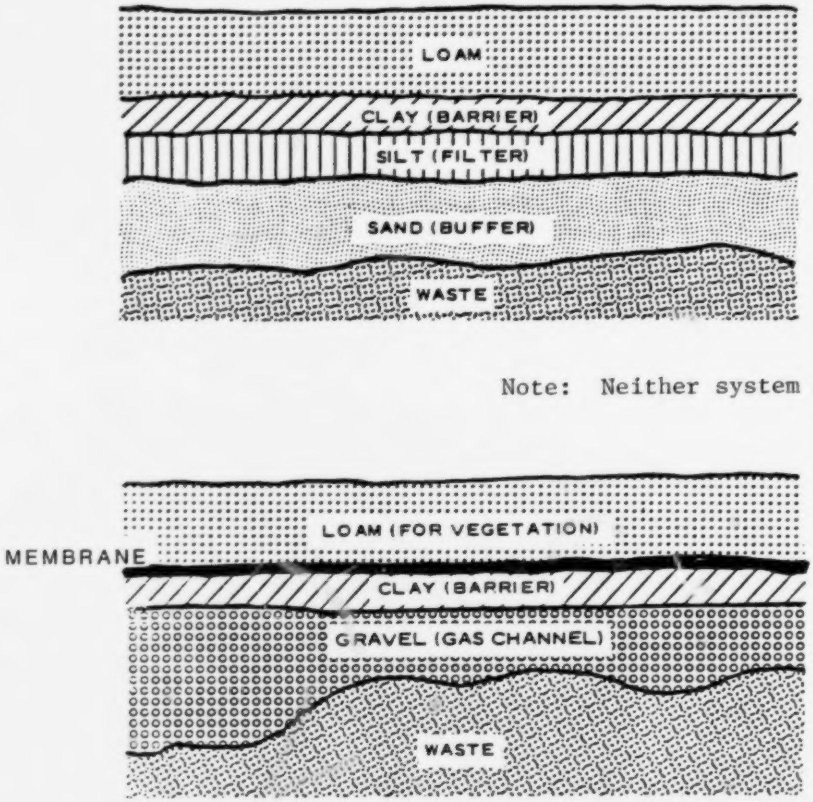
a. A clay hydraulic barrier underlain by a granular capillary buffer.

b. A synthetic membrane overlain by a coarsely granular drainage layer.

c. A resistant cap on a thick cover of nonselect soil.

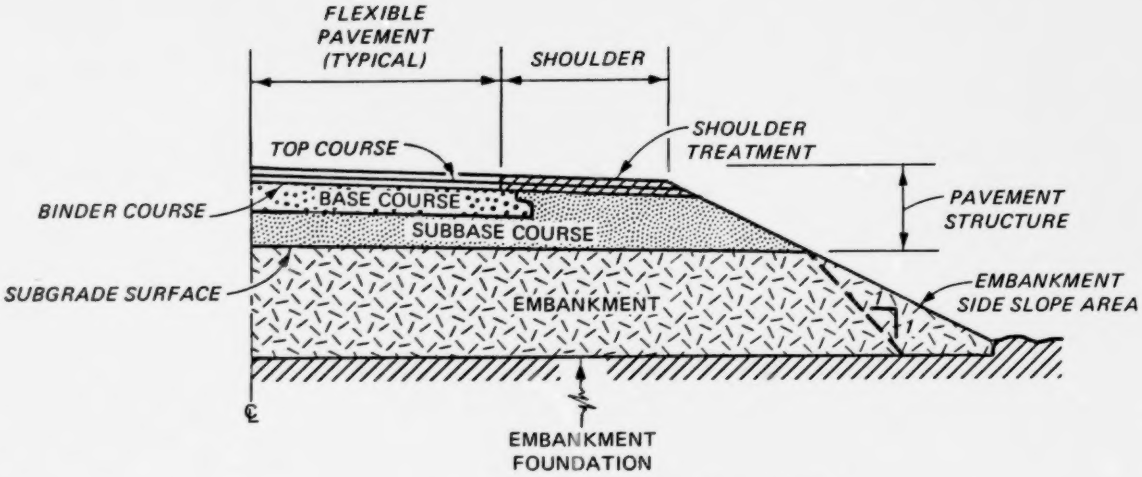
Additional explanations of layered cover options are found under EXAMPLE DESIGNS.

Water flows through unsaturated soil (including cover systems) according to a modified form of Darcy's law in which k is a nonlinear function of water content θ , i.e., $k(\theta)$. An important (and not immediately obvious)

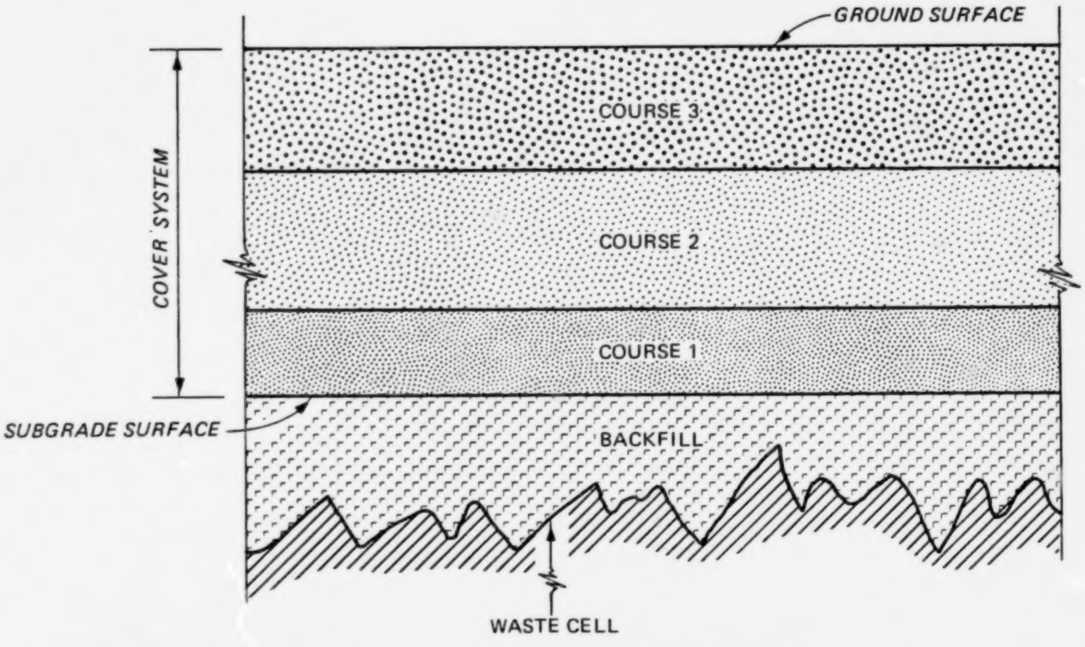

LOAM
CLAY (BARRIER)
SILT (FILTER)
SAND (BUFFER)
WASTE
LOAM (FOR VEGETATION)
MEMBRANE
CLAY (BARRIER)
GRAVEL (GAS CHANNEL)
WASTE

Note: Neither system satisfies RCRA

Figure 12. Schematic layered cover systems.


FLEXIBLE PAVEMENT (TYPICAL)
SHOULDER
TOP COURSE
SHOULDER TREATMENT
BINDER COURSE
BASE COURSE
SUBBASE COURSE
PAVEMENT STRUCTURE
SUBGRADE SURFACE
EMBANKMENT
EMBANKMENT SIDE SLOPE AREA
1
℄
EMBANKMENT FOUNDATION

a. HIGHWAY PAVEMENT SYSTEM


GROUND SURFACE
COVER SYSTEM
COURSE 3
COURSE 2
COURSE 1
SUBGRADE SURFACE
BACKFILL
WASTE CELL

b. WASTE COVER SYSTEM

Figure 13. Similarity between highway embankment and cover system.

manifestation of the effect of k and its dependency on Θ occurs in layered systems of contrasting soil types (15). When a wetting front, moving downward in an unsaturated soil of relatively fine pore sizes, contacts a predominantly large-pore soil, the pore volume capable of holding water at the suction pressure existing at the wetting front is reduced. Before the wetting front can advance, the suction pressure in the upper layer must decrease until it is low enough to allow the pores to fill with water. This delay continues until the upper layer approaches saturation at which time the water is believed to descend along localized channels rather than as a planar wetting front. Where the coarsely pored soil overlies the finer layer, a similar process impedes flow to the evaporation surface above.

Use of Tests

The designer of cover should strive to formulate the required characteristics of cover materials in terms of the results of standard tests. Without this quantitative characterization, the cover design is difficult to evaluate, and construction is difficult to specify and control. Table 11 presents a summary of widely recognized or standard laboratory tests of soils and related material suggested for use in quantifying or evaluating cover designs. Some tests are for index properties while others define basic characteristics. Notice the preference for the standards of the American Society for Testing and Materials (16). Methods of the American Association of State Highway and Transportation Officials (AASHTO) are also available (17).

Attention has been focused elsewhere upon the complexities of choosing and conducting the tests suited to engineering waste facilities -- most critically those for the permeability of soil barrier layers. Any test can be misleading when its idiosyncrasies are not fully appreciated. This problem helps reemphasize the importance explained in Section 1 (PREVIOUS ENGINEERING GUIDANCE) of experienced engineers, i.e., the need for the perspective of technicians who recognize the unfavorable consequences of carelessness in testing or in application of test results.

Results of standard tests can be translated into design criteria. It is generally recognized, although not always appreciated, that soil properties have a considerable variability in comparison to those of other construction materials such as steel and concrete. The variability partly results from the fact that soils are natural whereas most other construction materials are manmade. Accordingly, it is common practice in soil construction to use supplementally index properties based on relatively inexpensive and rapid testing procedures or methods of estimation. Numerous tests can be made and the soil can be approximately characterized for its variability as well as average properties (23). Widely recognized index properties of soils are used in classifying according to the USCS. Discussions of that system and its basis are found in many sources and, therefore, a summary is not repeated here.

See SOIL COMPACTION (SECTION 6) for a discussion of how the important compaction or relative density tests enter into design and into construction to achieve design.

TABLE 11. LABORATORY SOIL TEST METHODS FOR ANALYSIS AND DESIGN

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
		Index and Classification Tests	
Gradation Analysis	ASTM D421 D422 D2217	Particle size distribution	
Percent Fines	ASTM D1140	Percent of weight of material finer than No. 200 sieve	
Atterberg Limits	ASTM D4318 D427	Plastic limit, liquid limit, plasticity index, shrinkage factors	
Specific Gravity	ASTM D854	Specific gravity or apparent specific gravity of soil solids	Can usually be estimated closely
Soil Description	ASTM D2488	Description of soil from visual-manual examination	
Soil Classification	ASTM D2487	Unified soil classification	
		Moisture-Density Relations	
Dry Unit Weight	ASTM D2937 D698	Dry unit weight (dry density)	Either undisturbed or remolded samples
Water Content	ASTM D2216 D2974	Water content as percent of dry weight	
Relative Density	ASTM D4253 D4254	Maximum and minimum density of cohesionless soils	Modified test may be substituted for test with vibratory table
Compaction	ASTM D698 (or 5- to 15-blow modification)	Optimum water and maximum density	Method for earth and rock mixtures is given in Reference 18

(continued)

TABLE 11 (continued)

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
		Consolidation and Permeability	
Consolidation**	ASTM D2435	One-dimensional compressibility, permeability of cohesive soil	
Permeability	ASTM D2434	Constant head permeability	For granular soils
	Reference 18	Falling head permeability	Pressure chamber optional
		Physical and Chemical Properties	
Mineralogy	Reference 19	Identification of minerals	Requires X-ray diffraction apparatus. Differential thermal analysis apparatus may also be used
Organic Content	Reference 20 ASTM D2974	Organic and inorganic carbon content as percent of dry weight	Where organic matter content is critical, D2974 results should be verified by wet combustion tests (Reference 20)
Soluble Salts**	Reference 21	Concentration of soluble salts in soil pore water	
Dispersivity	ASTM D4221 Reference 22	Dispersion tendency in cohesive soils	Significant in evaluation of potential erosion of piping
		Shear Strength and Deformability	
Unconfined Compression**	ASTM D2166	Undrained shear strength	Applicable to cohesive soil only

(continued)

TABLE 11 (continued)

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
Direct Shear, Consolidated-Drained**	ASTM D3080	Effective shear strength parameters, cohesion and angle of internal friction	
Triaxial Compression, Unconsolidated-Undrained**	ASTM D2850	Undrained shear strength parameters, cohesion and angle of internal friction	
Triaxial Compression, Consolidated-Undrained**	Reference 18	Undrained shear strength parameters, cohesion and angle of internal friction	Effective shear strength parameters obtained if pore pressure is measured

*ASTM: American Society for Testing and Materials.
**Specialized test assigned only to obtain input for special engineering analysis and design.

Specifications and Plans

Construction and operation specifications are the vehicles for carrying cover design to fruition. Specifications may emphasize construction methods or end results but most commonly use a combination of both. Strong emphasis needs to be placed on performance standards, but at some point or some level between the legislature or regulating agency and the constructor of the cover, specific directions on cover construction and maintenance must be provided. This step has often been ignored or shortcut in the past so that many "plans" have been little more than conceptual in nature. Therein lies the cause of many of today's problem sites. Plans and specifications not only clarify the actual construction of the cover, but also they force the cover designer to quantify the design and face head-on any weaknesses, e.g. details of interfaces within the layered system.

Table 12 provides a partial list of technical provisions for cover construction. The organization is adapted from that offered as guidance by the AASHTO (13) for highway construction. The similarity of cover systems to highway systems (Figure 13) justifies this adaptation. Other sets of technical provisions may be used, or entirely new provisions may be developed. Table 13 presents items that are frequently included in a set of plans. Each

TABLE 12. TECHNICAL PROVISIONS OF CONTRACTS SUGGESTED FOR COVER CONSTRUCTION

PART 200 - EARTHWORK

SECTION 201 - CLEARING AND GRUBBING
" 202 - REMOVAL OF STRUCTURES AND OBSTRUCTIONS
" 203 - EXCAVATION
" 204 - BACKFILL AND EMBANKMENT*
" 205 - SUBGRADE PREPARATION*
" 206 - PREWATERING OF EXCAVATION
" 207 - STRUCTURAL EXCAVATION
" 208 - TEMPORARY EROSION AND WATER POLLUTION CONTROL

PART 300 - PRIMARY COURSE(S)

SECTION 301 - CLAY BARRIER*
" 302 - CLAY-MODIFIED BARRIER
" 303 - SYNTHETIC MEMBRANE BARRIER*
" 304 - BLOCK BARRIER*
" 305 - PAVEMENT

PART 400 - SECONDARY COURSE(S)

SECTION 401 - BUFFER LAYER
" 402 - STONE PROTECTION*
" 403 - FILTER LAYER*
" 404 - FILTER FABRIC (IN PLACE)*
" 405 - DRAINAGE LAYER*
" 406 - VEGETATIVE LAYER*
" 407 - SPECIAL FOUNDATION

PART 600 - MISCELLANEOUS CONSTRUCTION

SECTION 601 - CONCRETE FOR MINOR STRUCTURES AND INCIDENTAL CONSTRUCTION
" 602 - REINFORCING STEEL
" 603 - CULVERTS AND STORM DRAINS
" 604 - MANHOLES, INLETS, AND CATCH BASINS
" 605 - UNDERDRAINS
" 606 - GAS VENTS
" 607 - FENCES
" 609 - CURB, CURB AND GUTTER, PAVED DITCHES, AND PAVED FLUMES
" 610 - TURF ESTABLISHMENT*
" 611 - FURNISH AND PLANT TREES, SHRUBS, VINES, AND GROUNDCOVERS
" 612 - MOBILIZATION
" 613 - SLOPE PROTECTION
" 615 - EROSION CHECKS
" 616 - RIPRAP
" 617 - REFERENCE MARKERS
" 618 - TRAFFIC CONTROL

PART 700 - MATERIALS DETAILS

SECTION 701 - HYDRAULIC CEMENT
" 702 - BITUMINOUS MATERIALS*
" 703 - AGGREGATES*
" 704 - SPECIAL SOIL MATERIALS*
" 705 - STONE BLANKET PROTECTION AND FILTER BLANKET*
" 706 - MASONRY UNITS
" 707 - JOINT MATERIALS
" 708 - CONCRETE, CLAY, AND FIBER PIPE
" 709 - METAL PIPE
" 710 - SHEETING*
" 711 - GROUND COVER MATERIALS*
" 713 - CONCRETE CURING MATERIALS AND ADMIXTURES
" 714 - MISCELLANEOUS

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*Section or subsection is given in example specification in Appendix A.

TABLE 13. PLANS OF CONTRACTS SUGGESTED FOR COVER CONSTRUCTION

Item*	Description
1	Site location, large and small scale
2	Existing topography with elevations, monuments, roads, and grid lines or points
3	Soils data including boring logs, classification data, and soil properties
4	Locations of underground obstructions and existing utilities
5	Waste cells in plan and profile at scale suitable for measuring area and volume
6	Planned final topography (or profile lines)
7	Stockpile and storage areas and access
8	Vertical design(s) and extent of applicability
9	Methods of stabilizing weak foundation materials
10	Hydrological data and site drainage including runon
11	Cover drainage system including structures
12	Special features, such as gas venting system with construction details
13	Areas to receive topsoil and to be seeded
14	Vegetation or surfacing plan

*Other items to be added as needed.

item deserves one or more separate sheets, and complex systems frequently need numerous detailed drawings to explain all aspects and variations.

Specifications and plans also provide the necessary basis for evaluating proposed designs and for evaluating the construction procedures. It is relatively easy to foresee poor construction where clear specifications are not being followed. Conversely, clear documents prevent the contractor from being unfairly penalized when modifications in design and construction are required. Appendix A presents guidance on preparing specifications.

Well-conceived, formal plans and specifications can have value even where not directly applicable as part of a contract. Owners or operators accomplishing construction in-house rather than on contract should find that such concise directions simplify their construction program and associated interactions within the organization. They may choose to prepare operational plans that resemble contract plans and specifications.

EXAMPLE DESIGNS

The stratification of five example cover systems and a method for cover designation are shown in Figure 14. Four designs are relatively simple and their technical usefulness is expected on the basis of past experience at disposal facilities or according to well established principles of soil mechanics and soil physics. Flexibility remains to the extent that the thickness and details of material types may be manipulated according to site and waste characteristics. The fifth example design in Figure 14 is taken from Figure 2 and is reflective of RCRA requirements.

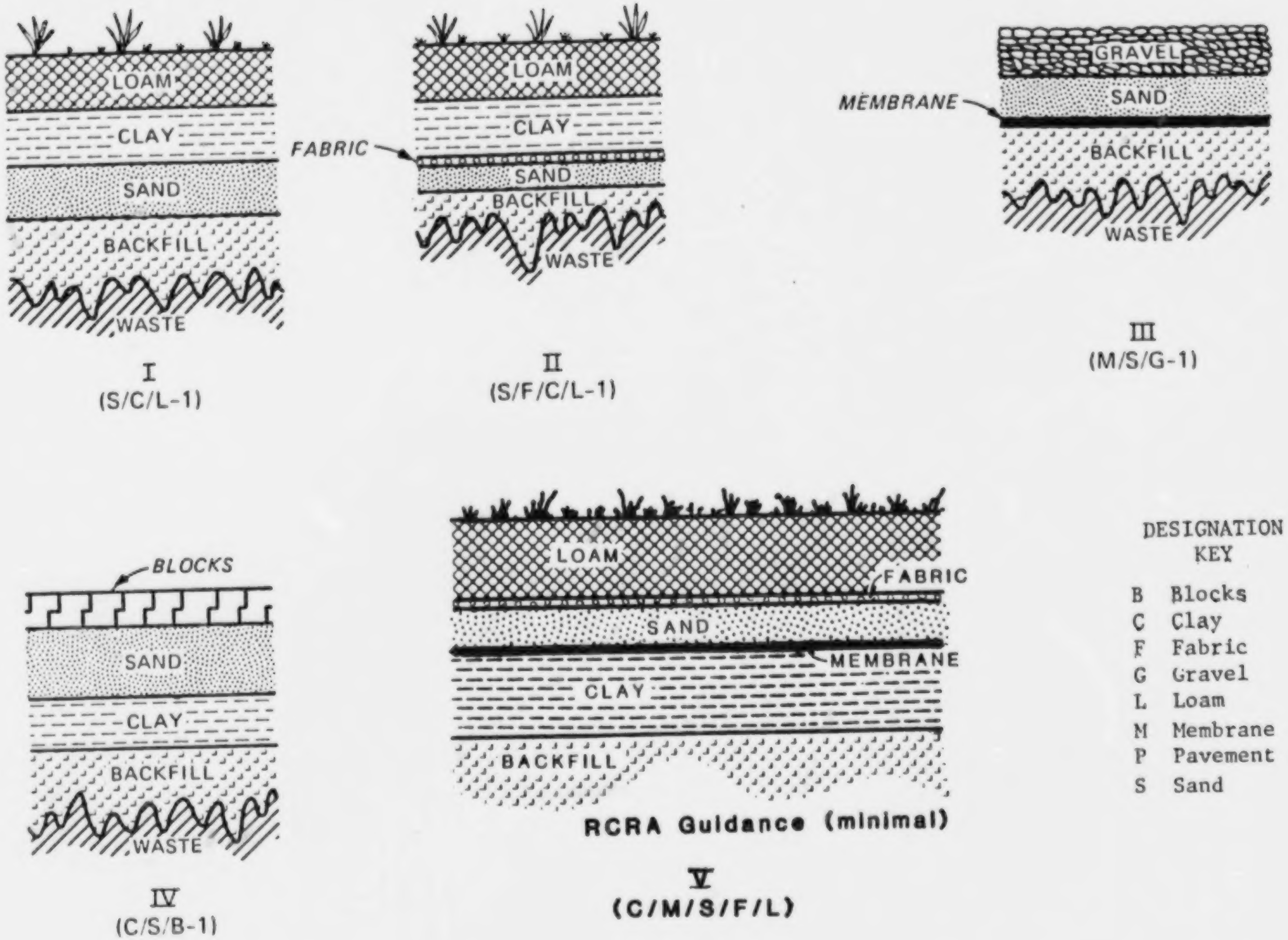
Appendix A provides guidance on preparing specifications for four of these example designs. The preparation of plans and specifications demands careful attention to detail, and sometimes the choice of wording can have costly legal ramifications. Therefore, the specifications in the appendix as well as the designs themselves should be regarded as intended for guidance rather than for direct application at any facility.

As can be seen in Figure 14, design I consists of layers of loam, clay, and sand from top down to the foundation of backfill soil and intermediate cover. The compacted clay layer constitutes the main, barrier component rejecting a large percentage of infiltrating water. The loam layer at the top supports vegetation and protects the clay layer. The sand layer below the clay barrier forms a supplemental capillary barrier and also protects from long-term deterioration by downward migration of clay particles. This design is more applicable to flat cover systems.

Design II is similar in makeup to design I but is made more refined by the inclusion of a synthetic fabric at the base of the clay layer. This fabric allows the use of a coarser, more effective capillary barrier in place of sand in design I. Without the fabric between the clay and coarse sand layers, clay particles may migrate downward with infiltrating water. The fabric also imparts some tensile and shear strength to the clay layer, and therefore the system may have advantages on gentle slopes.

Design III consists primarily of an impermeable membrane on the backfill soil foundation. The membrane is overlain by sand, which provides protection to the membrane and pathways for lateral drainage of infiltrating water. The surface layer consists of clean gravel or washed stone for protection against erosion. Soil below the membrane should be free of pebbles and larger pieces that might damage the membrane. This cap with its synthetic membrane would satisfy at least some requirements of RCRA regulations.

Design IV consists primarily of a hard cap on layers of granular soil and clayey soil. The clayey soil, which might be a glacial till such as is common in the northern United States, serves as the barrier layer. The granular soil layer provides an avenue of escape for water blocked by the barrier layer below. The hard cap, composed of blocks of concrete, asphalt, or other


LOAM
CLAY
SAND
BACKFILL
WASTE
FABRIC
LOAM
CLAY
SAND
BACKFILL
WASTE
MEMBRANE
GRAVEL
SAND
BACKFILL
WASTE
BLOCKS
SAND
CLAY
BACKFILL
WASTE
LOAM
FABRIC
SAND
MEMBRANE
CLAY
BACKFILL

I
(S/C/L-1)

II
(S/F/C/L-1)

III
(M/S/G-1)

IV
(C/S/B-1)

RCRA Guidance (minimal)

V
(C/M/S/F/L)

DESIGNATION
KEY

B	Blocks
C	Clay
F	Fabric
G	Gravel
L	Loam
M	Membrane
P	Pavement
S	Sand

Figure 14. Example cover designs.

resistant material, is intended to protect against erosion and to reject most rainfall as rapid runoff. The discontinuous (blocky) nature gives design IV a decided advantage over other hard caps considered in the past which are inflexible or adjust to settlements in an unpredictable manner.

Design V designated C/M/S/F/L is the only one in Figure 14 that explicitly addresses RCRA guidance (1). No specifications are given for this cover in Appendix A in order to prevent direct application with insufficient technical analysis.

ENGINEERING ANALYSES

Cover designs are checked and refined or revised to site specifics by the use of engineering analyses. The principal concern is for percolation characterization, but processes that may degrade the cover also deserve attention.

Percolation

Increments of water entering and leaving the cover system during increments of time can be balanced or partially balanced by changes in stored water. This process of water balancing has been mathematically modeled. the HELP model, designed specifically for the analysis of waste disposal units and their covers, is recommended as the best analytical tool to date. The HELP model culminated the modeling work started in the first of the two previously cited EPA reports (2). The HELP model and its application have been described thoroughly in a users' manual and program documentation (24,25). These descriptions are not repeated here.

Although the HELP model has been promoted for use in predicting water movement through cover and waste together, it is preferred here that use be limited for the present to the cover only. Accordingly, the prediction of percolation passing through the cover and into waste disposal units are sufficient for evaluating the cover. Conditions in the hydrological system below the cover cannot be observed directly. Clearly the more of the hydrological system that is included and analyzed, the greater will be the involvement of complex factors and in turn the less confidence can be put in results.

The accuracy of the HELP model has not been verified by comparison with actual measurements in comparable increments. Portions of the Department of Agriculture CREAMS model, through which the HELP model evolved, have compared favorably with field measurements for runoff. Also, the subtraction for evapotranspiration on a daily basis is accomplished with a physically well based model.

It is suggested that one effective way of using the HELP model in cover design is to prepare a chart or tabulation giving monthly or annual totals of percolation for several cover designs or variations under consideration. This analysis can be repeated for wet and dry years as well as being used for average conditions. Table 14 shows an example of this sort of comparison actually used in RCRA enforcement proceedings to compare the effectiveness of three remedial cover designs.

TABLE 14. ANALYTICAL COMPARISON OF COVER DESIGNS AGAINST PERCOLATION*

Period	Annual Precipitation (in.)	Calculated Annual Percolation and (Runoff) (in.)		
		$K = 7 \times 10^{-6}$	1×10^{-6}	1×10^{-7} (cm/s)
1974-78	38.19	4.95 (1.78)	3.38 (2.13)	0.89 (2.35)
1979	66.46	15.84 (12.23)	8.02 (17.38)	1.14 (20.15)

*Cover design consists of 12-in. loam layer on 12-in. compacted clay layer (K as specified) on 24-in. sandy clay over waste. Good grass facilitates evaporation to 12-in. depth. Location is in southeastern US. Calculated by HELP model.

Areal Erosion

An empirical analysis of erosion potential has been developed (26) for predicting soil loss from certain ground configurations and soil types. The method uses the so-called universal soil loss equation. Application to cover design has been described elsewhere (2) and is still recommended. The use of this analysis, however, should be tempered by the realization that a designer wants erosion to stabilize at negligible levels in only a few years. Erosion of many tons of sediment from a waste disposal facility is unacceptably excessive; therefore application of analyses primarily intended for use on eroding croplands may be somewhat misleading and should be interpreted with care.

Flooding

Hydraulic analyses are usually needed to quantify possible flooding and to predict erosion along channels, adequacy of ponds and structures, and overflow onto unprotected areas of the cover. Measures against severe gullying may also come from this analysis. Analyses are first accomplished for the site in general (HYDROLOGY, SECTION 2) but deserve careful review in the narrower context of cover survivability and performance.

A hydraulic analysis combines the hydrological background, especially infrequent heavy storm events, with watershed characteristics to model the probable extreme flooding at the site in the future. Temperatures may need to be factored in since freezing can reduce percolation and exaggerate otherwise minor runoff events. The principal aspects of the cover system in question are usually the drainage network and the capacity of its structures and channels. Vulnerability may also be manifested in low resistance of cover materials to erosion by high-velocity floodwater.

Design storm data are readily available for any location, and it is reasonable to expect site documentation to include several extreme rainfalls for recurrence intervals of possible interest. For an average size landfill a 1-hour storm and storms of longer duration are of typical interest. One recurrence interval would likely be 10 or 20 years, but the reasons should be presented for choosing specific intervals and storm durations. Figure 15 is an example of summary information available for checking design storm amounts. Design life discussed in Section 2 may impact directly; e.g., a 200-year, 2-hour storm may be appropriate for analyzing a facility intended to function for 200 years. Where contingencies for repairs are adequate, a 20-year storm may be sufficient.

The sequel to the assembling of design storm data is the calculation of flood discharges for ditches and other elements of the drainage system. The calculation in simplest form utilizes the rational equation:

$$Q = C_{RO}\ i\ A$$

where

Q = peak discharge, cubic feet/second
C_{RO} = runoff coefficient
i = rainfall intensity, inches/hour
A = area of basin, acres

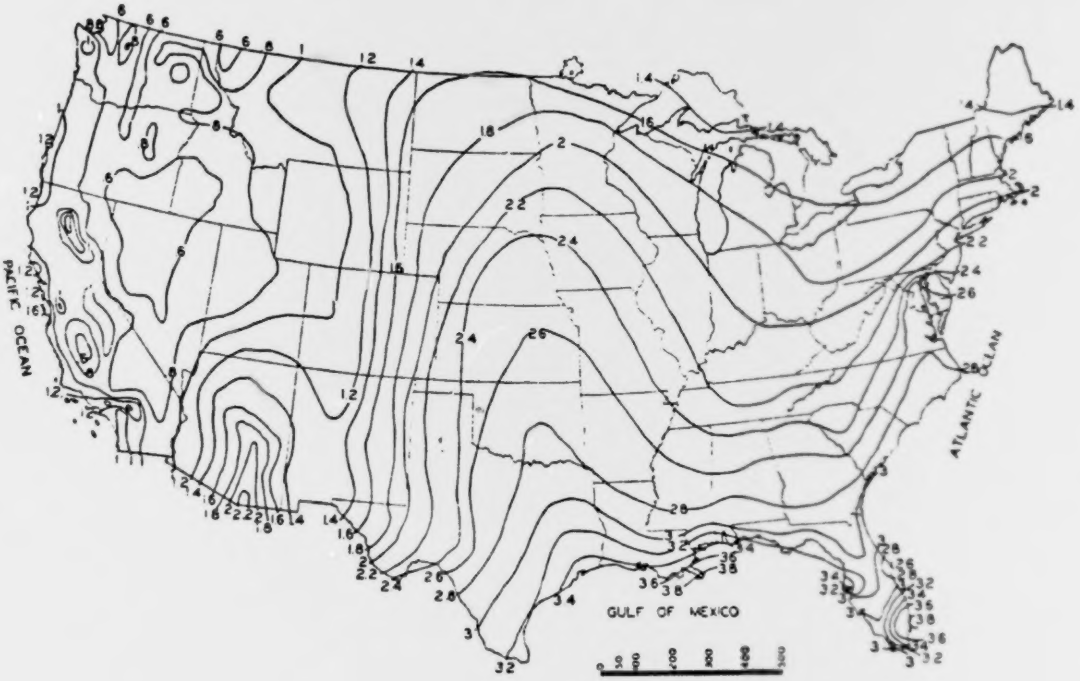


Figure 15. Ten-year, 1-hour rainfall in inches (US Weather Bureau).

The formula above incorporates the approximation that 1 inch/hour/acre = 1 cubic foot/second. Roughly approximated, the C_{RO} values for vegetated clayey soil on flats and slopes are about 0.5 and 0.7, respectively, and for vegetated sandy soils on flats and slopes are about 0.2 and 0.4.

Where an upstream watershed area greatly exceeds the disposal area and the concern is for flooding in a channel passing alongside a disposal unit, analysis may produce a hydrographic history including a flood crest. Analyses of this type are also fairly straightforward, but it will be essential that the analysis be conducted by an engineer with experience in its conduct and application including both large and small watersheds.

The conclusions of the analysis should be such as to suggest the potential threats from flooding. Modifications in design may become evident that will help avoid intolerable immersion or erosion of portions of the cover system during the design life.

Slope Stability

Engineering analyses of slope stability are based on the concept that a slope fails, unless the resultant resistance to shear on every possible surface traversing the fill is greater than the resultant of all shearing forces exerted on that surface by the mass above. The surface that is most likely to fail is called the critical surface. The factor of safety (FS) quantifies the ratio of resisting forces to driving forces. Stability analysis is a sophisticated technique requiring geotechnical engineers, often using soil test and other field-sampled data as input. Most analytical and test work should be accomplished by such specialists. However, it is sometimes also imperative that an engineer closer to the design and construction of the cover system contribute to the analyses to keep them from being expensive with useless embellishments.

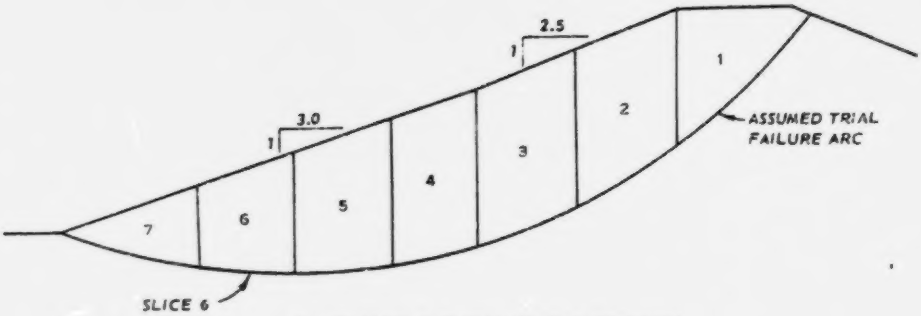
Determination of the location of the critical surface usually requires successive trial analyses of likely candidates. Each trial evaluates a surface having one of the following shapes:

a. Circular arc (Figure 16) within the foundation and/or the embankment.

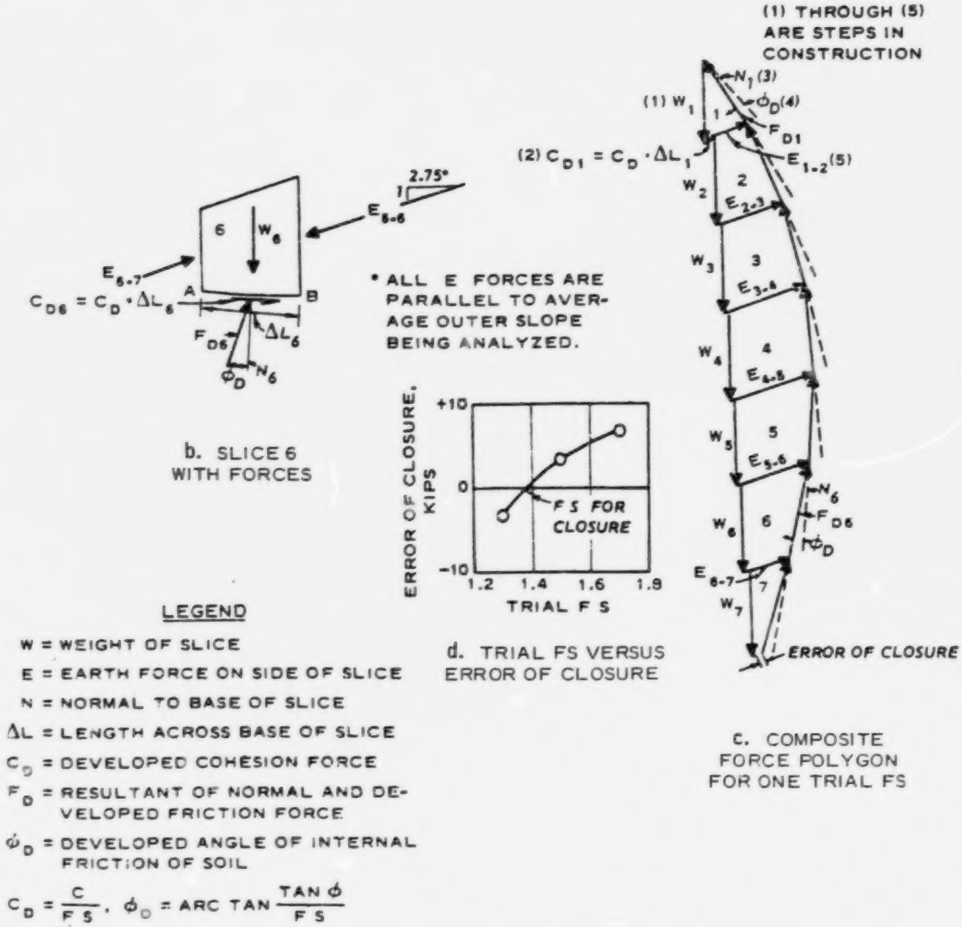
b. Composite of a long horizontal plane in a foundation stratum connecting with diagonal planes up through the foundation and embankment to the ground surface.

c. Plane paralleling the ground surface at shallow depth.

Analyses assuming a circular arc failure surface may be made using either the modified Swedish method that considers forces on the sides of vertical slices within the mass (Figure 16) or the simpler Swedish method of slices that assumes that side forces are equal in magnitude and parallel to the base of each slice. The wedge method for planar sliding surfaces (Figure 17) is appropriate for weak foundations requiring flat slopes or for an otherwise strong foundation containing a thin weak stratum. Appropriate forces for ground water are incorporated below the water table. Water forces tend to


2.5
1
3.0
1
1
2
3
4
5
6
7
ASSUMED TRIAL FAILURE ARC
SLICE 6

a. EXAMPLE EMBANKMENT SECTION

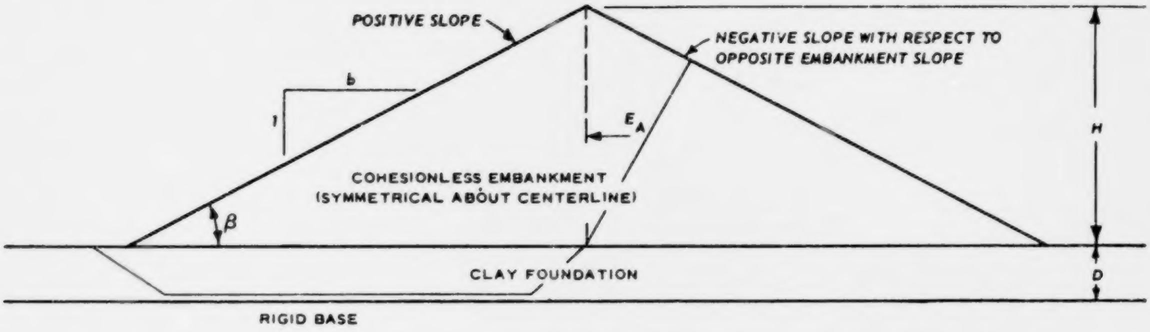

(1) THROUGH (5) ARE STEPS IN CONSTRUCTION
N_1(3)
ϕ_D(4)
(1) W_1
F_{D1}
(2) $C_{D1} = C_D \cdot \Delta L_1$
E_{1-2}(5)
W_2
E_{2-3}
W_3
E_{3-4}
W_4
E_{4-5}
W_5
E_{5-6}
N_6
F_{D6}
ϕ_D
W_6
E_{6-7}
W_7
ERROR OF CLOSURE
2.75*
1
E_{5-6}
W_6
E_{6-7}
A
B
$C_{D6} = C_D \cdot \Delta L_6$
F_{D6}
ΔL_6
ϕ_D
N_6
* ALL E FORCES ARE PARALLEL TO AVERAGE OUTER SLOPE BEING ANALYZED.
ERROR OF CLOSURE, KIPS
+10
0
-10
1.2
1.4
1.6
1.8
TRIAL F S
F S FOR CLOSURE
LEGEND
W = WEIGHT OF SLICE
E = EARTH FORCE ON SIDE OF SLICE
N = NORMAL TO BASE OF SLICE
ΔL = LENGTH ACROSS BASE OF SLICE
C_D = DEVELOPED COHESION FORCE
F_D = RESULTANT OF NORMAL AND DEVELOPED FRICTION FORCE
ϕ_D = DEVELOPED ANGLE OF INTERNAL FRICTION OF SOIL
$C_D = \frac{C}{F\,S}$, $\phi_D = \text{ARC TAN} \frac{\text{TAN}\,\phi}{F\,S}$

b. SLICE 6 WITH FORCES

d. TRIAL FS VERSUS ERROR OF CLOSURE

c. COMPOSITE FORCE POLYGON FOR ONE TRIAL FS

Figure 16. Modified Swedish method of finite slice procedure with no water forces (27).


POSITIVE SLOPE
NEGATIVE SLOPE WITH RESPECT TO OPPOSITE EMBANKMENT SLOPE
b
1
E_A
H
COHESIONLESS EMBANKMENT (SYMMETRICAL ABOUT CENTERLINE)
β
CLAY FOUNDATION
D
RIGID BASE

H = HEIGHT OF EMBANKMENT
D = THICKNESS OF CLAY FOUNDATION LAYER
K_A = RATIO OF HORIZONTAL TO VERTICAL EARTH PRESSURES, ACTIVE CASE
b = COTANGENT OF SLOPE ANGLE, β
y = WEIGHT OF EMBANKMENT AND FOUNDATION MATERIAL PER UNIT OF VOLUME
c = COHESION PER UNIT AREA OF FOUNDATION SOIL

Figure 17. Conceptual cross section and symbols for wedge analysis

reduce stability by increasing the driving forces and decreasing the resisting forces due to uplift. In the case of steady seepage, the water force acting on each slice is determined from flow nets or assumed to vary linearly below the saturation line.

A special, simple analysis is available for cohesionless soil embankments. The infinite slope procedure (27) addresses rather shallow sliding and may be appropriate for relatively thin granular cover over sloping waste where shallow sliding can be serious. For dry conditions, the safety factor reduces to

$$FS = \frac{\tan \phi}{\tan \beta}$$

where β is slope inclination and ϕ is material friction angle. The equivalence of the ϕ and β at the threshold of failure is reflected in the general correspondence of the observed angle of repose and measured ϕ in cohesionless soils (Table 15).

Freezing

The most serious freezing effects are cracking or buckling of layers, sliding after thawing, and blocking of vents and drains. Also see Flooding for effects of freezing on runoff. Since these problems are all limited to the near-surface zone actually subject to freezing, a key characteristic to be

TABLE 15. ESTIMATES OF REPOSE AND FRICTION ANGLES OF COHESIONLESS SOILS

		Friction Angle, deg	
Soil Description	Angle of Repose* deg	At Ultimate Strength	At Peak Strength
Silt	26 - 30	26 - 30	28 - 34
Uniform sand	26 - 30	26 - 30	30 - 36
Well-graded sand	30 - 34	30 - 34	34 - 46
Sand and gravel	32 - 36	32 - 36	36 - 48

*Lower values generally for soft or well-rounded particles at dense packing or at high normal stresses.

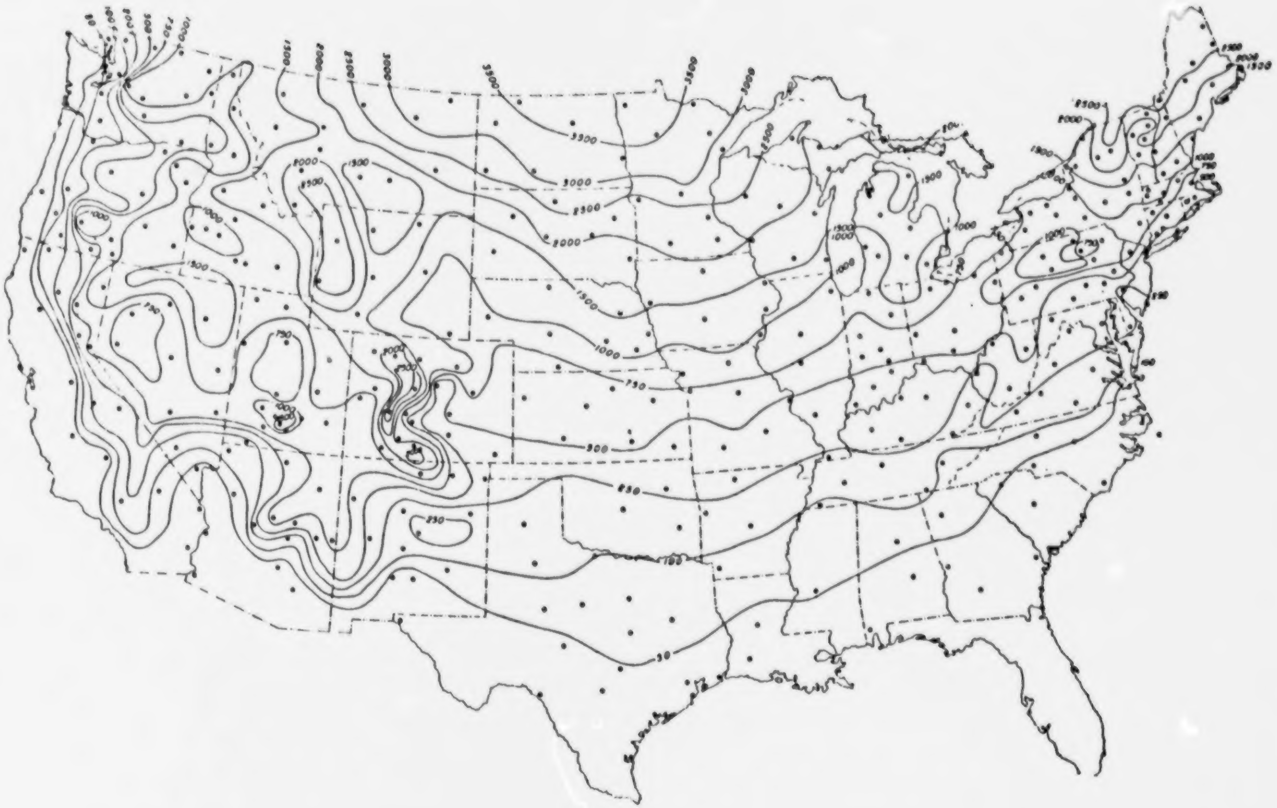
factored into design is the depth of freezing. As long as vulnerable elements of the cover system are not placed above the depth of freezing, the effects are not serious.

Numerous weather stations record soil temperature profiles routinely. The analysis for freezing depth has also been developed empirically using past climate records much the same as storm data have been used in flooding analyses. An essential intermediate parameter is the freezing index. The index is computed in degree-day units by summing cumulatively the values for each day over a freezing season. The daily values are simply the differences between mean air temperature and freezing temperature (32°F).

Figure 18 shows freezing indices for the conterminous United States for the coldest year in a 10-year cycle or the average of the three coldest in a 30-year cycle. The nearly 400 US Weather Bureau stations that were used for basic data are spotted in the figure. A site-specific design freezing index should be used in preference to those in the figure wherever nearby stations are available because differences in elevation and topographic position and nearness to cities, bodies of water, or other sources of heat produce considerable variations in the index over short distances. These variations are particularly important to design in areas of indices of less than 1000, i.e., in much of the United States.

The maximum depth of frost penetration can be predicted in a general way on the basis of the freezing index. For example, Figure 19 shows generalized curves for a direct relationship at various soil conditions. This information should be helpful in choosing thickness for various final cover soils.

It is also appropriate to consider applying the freezing index for periods of one or a few days rather than an entire cold season. For example, an unfrozen silty sand placed on solid waste may be expected to freeze to a depth


50
100
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250

Figure 18. Design freezing index values in degree-days for the conterminous United States.

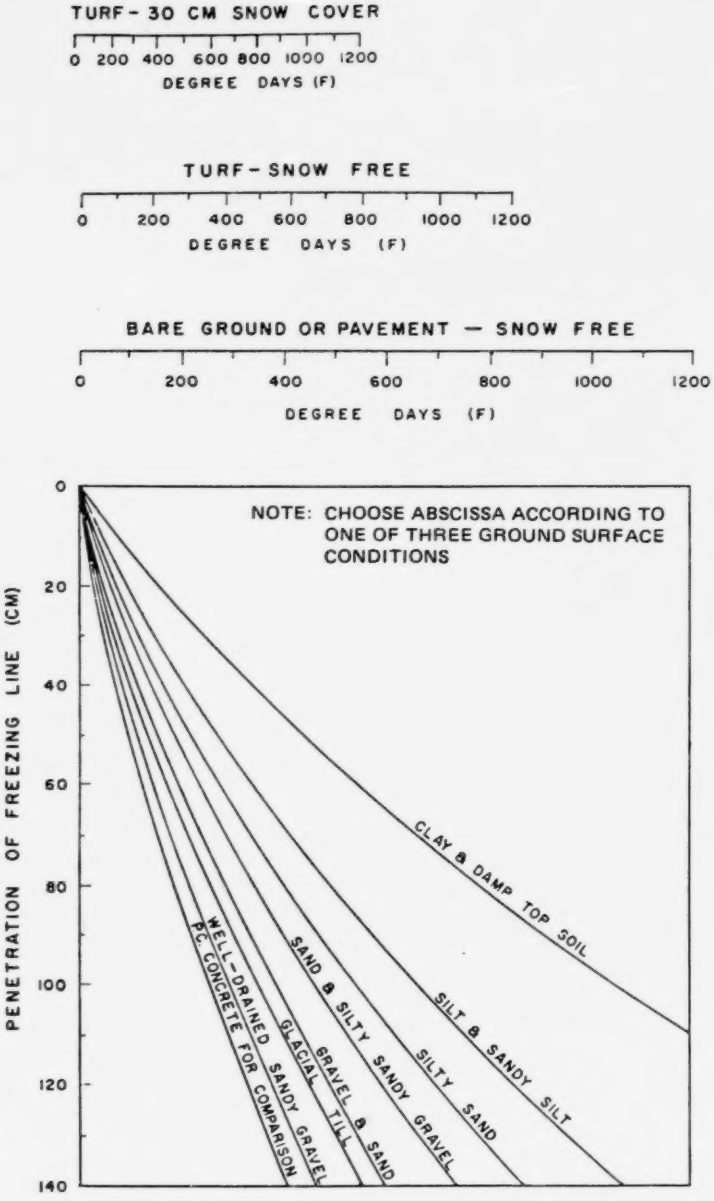


Figure 19. Depth of freezing penetration into soils with bare or covered surfaces.

of 20 centimeters during 10 days in which the mean daily temperature is 22°F (Figure 19). The index applies on a daily basis also in a very approximate way.

Settlement

Despite the extreme complexity of the settlement processes, displacements accumulating in the cover above a waste cell can be estimated with some confidence over the very short term and the very long term. Displacements ranging from areally uniform to abruptly discontinuous will directly reflect the void space able to participate in the volume reduction at the time. For example, 10 percent large voids should result ultimately in a 1-foot displacement over a 10-foot-thick waste cell. Large voids will be closed relatively soon, followed by smaller and smaller voids closed at decreasing rate. Therefore, the analysis depends on an accurate characterization of the waste cell. Unfortunately, the timing of the settlement over an intermediate period of many years is too complex for useful analysis.

Cost

Costs will be the most important category needing analysis to some users of this document. The facility owner who pays the bill most certainly will want careful attention to cost savings in design and construction. To others such as regulators, cost will be quite subordinate to technical concerns, but an interest in cost should be maintained even by regulators since less costly options in design and construction are frequently, though not always, less effective. Life-cycle costing will be important in long-term planning.

Since cost analysis depends more on individual skills than on technical routines, the qualifications of the analyst are often poorly defined. Experience in cost estimation for similar waste disposal or related earthwork construction would be an obvious asset. The analysis basically amounts to integrating unit costs and quantities for the various materials, equipment, and labor into total costs for each construction option under consideration. After appropriate adjustment for expected benefit, a decision is made on the best choice.

SECTION 4

LAYERED DESIGN ELEMENTS

This section reviews the several layer types that have been used in cover or that have been proposed for such use. Layer types are discussed in no particular order. There is no implication of relative importance of layers, nor is it implied that all types are needed in an effective cover. Emphasis is placed (Figure 14) on the use of no more layers than can be justified on the basis of experience, physical principles, and expected benefit-to-cost ratio. One should look with increasing skepticism upon designs of five, six, and more layers.

HYDRAULIC BARRIER

The hydraulic barrier layer is usually the most important element of the cover in other than arid regions. A coefficient of permeability $k = 10^{-7}$ centimeters/second or less by laboratory testing has been prescribed as necessary for soil barriers, but analytical tools are available to allow a refined prescription fitting the specifics of site climate and material types (See Percolation, SECTION 3). Barrier layers of soil are almost always composed of clayey soils that inherently have low permeability. USCS types CH, CL, and SC are generally recommended; also see Table 9. RCRA regulations are interpreted as requiring a synthetic membrane in the cover. Guidance (1) calls for both a membrane and a low-permeability soil layer, with the membrane as the primary barrier.

Soil

Tables 9 and 16 should be useful as guides in determining the relative effectiveness of various soils in impeding or passing water, but other factors such as shrinking and cracking characteristics or root-system development may complicate the choice. Well-graded granular soils have lower k values than poorly graded granular soils of the same median grain size. It has been suggested that in continuously graded gravel for highways (28) k is directly reflective of the nature of the fines passing the No. 200 sieve when they exceed 15 percent. For graded gravels with less than 15 percent passing No. 200, the effect of the fines is less direct.

Special attention and control are needed. The selection and use of clay material have tended to be loose or poorly controlled, and materials other than straight clay have been substituted frequently, e.g., till. This practice is sometimes even preferred since the combination of permeability and other physical properties of some of these substituted soils may be well suited to the cover system. Nevertheless, there is a clear need to be

TABLE 16. APPROXIMATE AVERAGE PERMEABILITY* AND CAPILLARY HEAD OF SOILS

General Soil Type	USCS Soil Type	Coefficient of Permeability, cm/s	Capillary Head, cm
Gravel	GP	10^{-1}	---
	GW	10^{-2}	6
	GM	5×10^{-4}	68
	GC	10^{-4}	---
Sand	SP	5×10^{-2}	---
	SW	10^{-3}	60
	SM	10^{-3}	112
	SC	2×10^{-4}	---
Silt	ML	10^{-5}	180
	MH	10^{-7}	---
Clay	CL	3×10^{-8}	180
	CH	10^{-9}	200 - 400+

*Compaction reduces permeability in general.

especially thorough in testing and other documentation of prospective clayey materials so that all parties know the facts. Considerations that deserve special attention are the geology, mineralogy, uniformity, and total available volume of the clay source.

Working design criteria for fine-grained, impervious, erosion-resistant linings such as lean clay (CL) for canals are presented in Figure 20. Although this confirmed guidance is recommended for consideration in cover design, the differences in function of an exposed canal lining from the buried barrier should be carefully investigated. The developers of the criteria (29) actually prefer gravelly soils in their added need for erosion resistance. In order, they prefer GM-GC and then GC, SW-SC, and SC. This practical experience indicates that gravelly or sandy soils will have sufficiently low k for barriers, again, provided the clay and intermediate size fractions are adequate.

If well-graded fine soil is not available nearby but coarse- and fine-grained soils are, blending should be considered. Properly blended soils are effective for increasing impedance to water movement since the grain-size distribution is broadened as compared with distributions of the component soils.

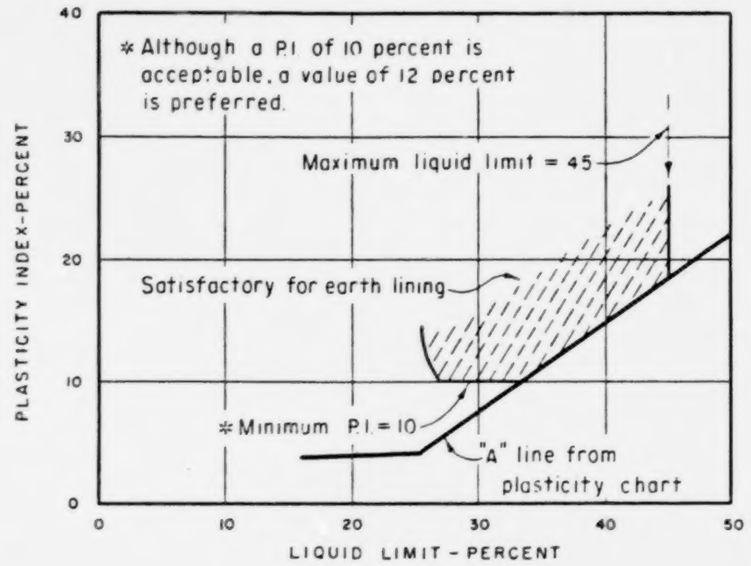


Figure 20. Plasticity criterion for impervious, erosion-resistant compacted canal linings (29).

Blending is usually an expensive operation, and a thorough review of other options may be advisable before proceeding on a large scale. Where a barrier layer of very low permeability is warranted, it may be necessary to modify the soil available at the site by addition of special material. The addition of bentonite to sandy cover soil substantially reduces k (Figure 21). A lesser reduction has been obtained in fly ash (31).

All soil barrier layers should be compacted to reduce permeability; 90-95 percent of standard compaction is a reasonable target for high-priority covers and careful construction control is needed. The porosity is decreased and some strengthening may also result. At municipal waste landfills, an effort of more than two passes of the spreading or compacting equipment may be impractical to monitor and regulate on daily cover. Higher compactive effort seems appropriate for intermediate and final covers except as it will interfere with establishing vegetation. Care should be taken to assure that the water content during compaction does not greatly exceed the optimum percentage. See Section 6 for practices in soil compaction and Appendix A for detailed specifications such as might be used at RCRA facilities.

The fine-grained soils that are suitable for blocking percolation are also characterized by susceptibility to cracking. The cracking accompanies large shrinkage brought about by a reduction in the high water content. High daytime temperatures at the ground surface are the most common cause, but freezing and thawing can bring about a redistribution of moisture also. It is usually effective to pair the soil barrier with an overlying buffer or other soil layer sufficient to dampen out the most severe movement of moisture

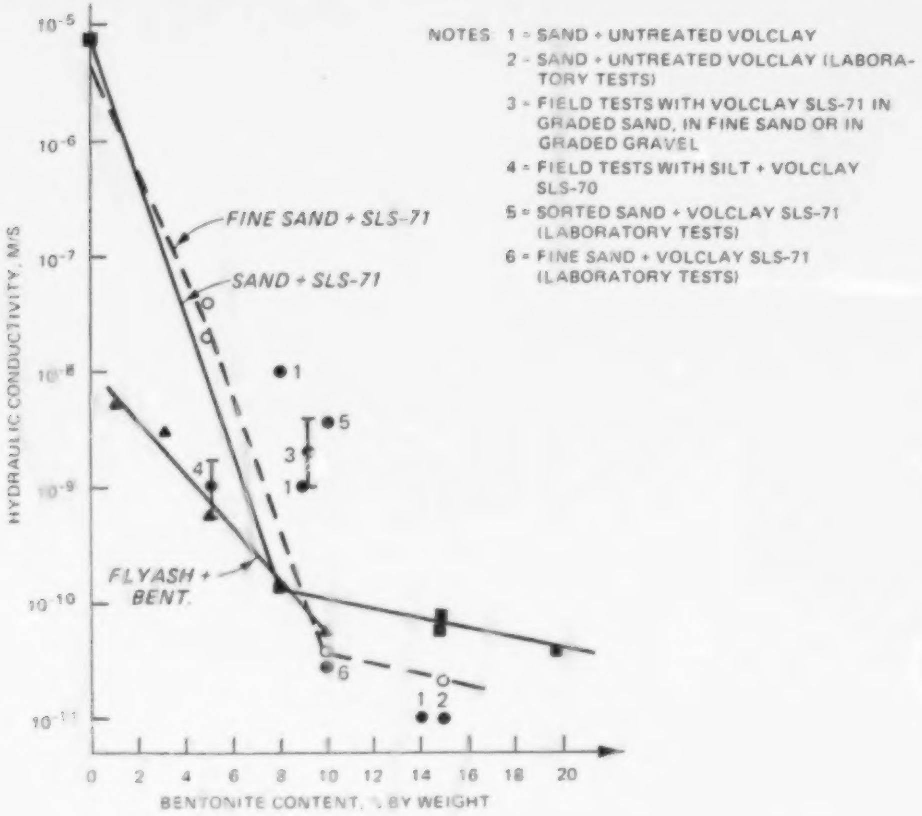


Figure 21. Effect of bentonite additions on permeability of granular soil (30).

(particularly drying) which otherwise culminates in cracking. The clay layer in a RCRA system such as in Figure 2 is shielded from surficial drying effects by the overlying synthetic membrane.

Some soils recover from cracking, e.g., when dry clay regains moisture, swells, and closes cracks. This behavior is sometimes popularized as "self-healing" in an exaggeration of what may actually be a very complex and partly unconfirmed process. Any infilling of foreign soil along cracks will tend to impede the recovery.

Damage to the barrier layer can also come about through differential settlement. One technique for protecting the barrier from effects of differential settlement consists of providing an adequate layer thickness to compensate for displacements which may possibly occur. This technique relies on the plasticity and swelling characteristics of the clay barrier to heal immediately any opening starting to develop along shears.

Membrane

Synthetic membranes are often used as the primary barrier layer and, in fact, are required for most RCRA covers. Guidance in the designation of membrane type by its attributes is beyond the scope of this document. Selection is a major task for technical analysis and deserves careful consideration by specialists familiar with properties of membranes as well as the needs at the disposal site. See the technical resource document SW-870 (32) for a review of membranes in liners also applicable to barrier layers in cover systems.

It is appropriate to mention some major technical concerns when using synthetic membranes: volatile stability, freezing effects, heating effects, temperature cycling, and tensile strength. The overall service life expected of the cover system reflects a complex summation of the individual effects. A facility design life of hundreds of years may exceed a reasonably expectable life for a membrane based on past experience and projections which are conservative in the engineering sense. However, current expectation is that longer service will be obtained as new, improved materials are developed. In any case, careful planning for maintenance and future repair is needed (SECTION 10). A list of detailed membrane requirements, even when partly in qualitative terms, will be very useful since these service requirements lead logically to a focusing of attention on the consequences of a gradual or rapid deterioration of the membrane.

VEGETATIVE LAYER

A preliminary step in establishing vegetation often is to plan measures to stockpile and then reuse the original topsoil. The less fertile underlying soil will be available for near-term use. As the operation nears completion, the stockpiled topsoil can be used in the final cover to facilitate rapid growth of grasses and shrubbery. The original topsoil must be significantly more fertile than underlying soil strata; otherwise, stockpiling is not practical or economical. It may be critical to protect stockpiled topsoil from excessive exposure that may damage essential microbial components. In fact, the stripping of topsoil is sometimes coordinated with placement in the cover system during a short interval in spring or fall to avoid this detrimental effect of stockpiling altogether.

Untreated subsoils are seldom suitable directly, so it is necessary frequently to supplement subsoil when it must be used with fertilizers, conditioners, etc. Loams or USCS types GM, GC, SM, SC, ML, and CL are recommended, but agronomic considerations usually prevail. The upper lift should be placed in a loose condition and not compacted. Other beneficial characteristics of vegetative soil are identified in Section 8 to which reference should be made in designing the layer.

At least 18 to 24 inches of plant growth medium is regarded as necessary to provide a reservoir of moisture at field capacity. Intermittent deficiencies or excesses of water need to be considered in designing the vegetative layer. Vegetation can exhaust moisture from a thin well-drained soil layer in a short time and then be severely stressed during droughty conditions. Certain configurations of soil, particularly over barrier layers, may experience localized saturation for extended periods. Under this circumstance roots may be killed quickly. Some relief from these extreme detrimental conditions may be found in features such as drainageways and in surface shaping.

Where experience is insufficient for presuming the survival of vegetation, a contingency may be needed in the plan for restoration or upgrading of stressed vegetation. Such a contingency might conceivably involve increasing the layer thickness (at substantial cost).

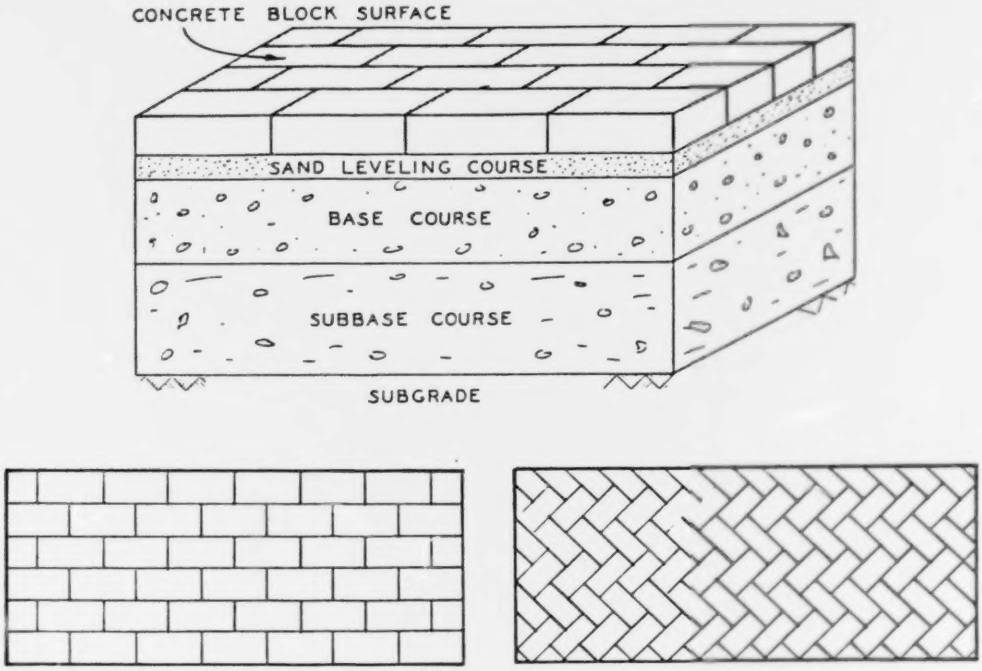
RESISTANT LAYER

The placement of a resistant cap at the ground surface is another technique for protecting against severe erosion damage. The wide variety of resistant materials offers broad ranges of performance and service life. Air-entrained concrete can be expected to survive as a material for hundreds of years in mild climates. Asphalt surface seals suffer relatively short-term deterioration by oxidation and loss of volatiles and traditionally need supplemental maintenance. Most man-made resistant layers placed in a continuous sheet will be subjected to at least some flexural and thermal stress and will sustain crack damage over a period of years. Crack sealing and other maintenance can constitute a substantial part of the overall cost of such layers even exceeding the cost of original installation.

Resistant layers composed of fitted blocks of durable material offer a possible compromise. Figure 22 is adapted from investigations on use for pavement (33). Blocks tend to be less susceptible to thermal stress damage and are self adjusting to flexure that may accompany subsidence of the waste below. A layer of fitted blocks provides an abundance of thin channels for infiltration of water. However, these channels constitute no more than a few percent of the total surface area and therefore are quite limited in their capacity to admit water. Most heavy rain falling on hard surfaces is rejected quickly as runoff. Nevertheless, a combination of surface and even subsurface drainage features will usually be necessary.

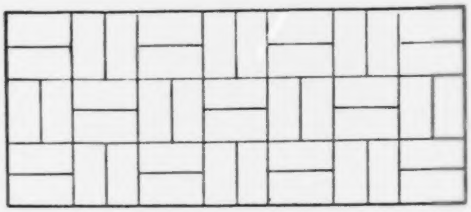
One of the most attractive resistant materials is gravel (Figure 23). Gravel is a highly durable, natural material that resists freezing disturbance and also serves to dampen other temperature- and moisture-related processes tending to degrade the cover system. Gravel is well established as construction material, and costs for stone protection can be estimated closely. Cost advantages are also present in maintenance since repair largely amounts to patching with more gravel. A commonly used specification for such gravel or crushed stone is as follows:

Sieve Designation	Weight Percent Passing
2 1/2 inches	100
2 inches	95-100
1 inch	35-70
1/2 inch	10-30
No. 4	0-5


CONCRETE BLOCK SURFACE
SAND LEVELING COURSE
BASE COURSE
SUBBASE COURSE
SUBGRADE

Stretcher bond

Herringbone



Parquet

Figure 22. Fitted blocks for surface paving or armor.

Specifications for another material as well as construction methods are given in Appendix A for design III (M/S/G-1).

Gravel and stone tailings from processing of sandy gravel are particularly attractive for protection of slopes, and it may be reasonable to use this material as a supplement to the more usual grass cover. Ordinarily gravel slopes inclined between 5 and 25 percent resist erosion indefinitely;

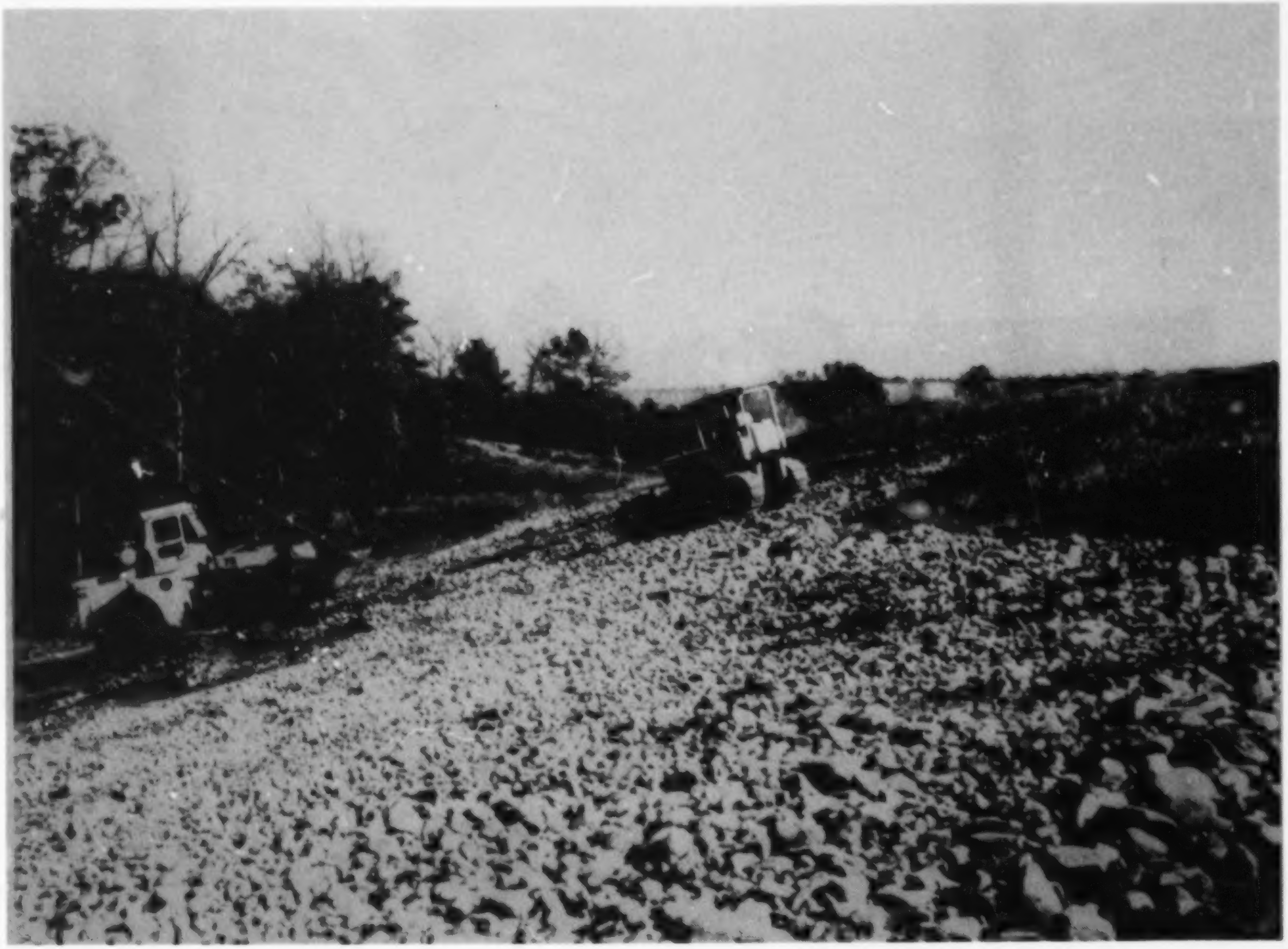


Figure 23. Washed gravel on slope at Windham landfill.

whereas flat areas under 5 percent should endure as well with the less expensive vegetative layer at the surface.

BIOBARRIER

Biobarrier is the term popularized for a layer intended to block penetration by animals or plants. The perceived threat is only occasionally serious and even then difficult to address quantitatively in design. Animals invade for access to food, protection, or favorable temperature. Plant roots descend to tap moisture needed for continued growth. Animal tunnels and plant root holes would seriously degrade the cover system if they penetrated the barrier layer. There may be special cases in which the penetration of the disposal unit and subsequent removal of moisture through evapotranspiration is a favorable condition, but for the present, the consensus is largely to the contrary. Other threats from animal and plant activity through the cover arise in possibilities for physical transport of hazardous waste to the surface by the animals and uptake of pollutants by the plants.

Materials suitable for resisting penetration by animals should have low cohesive strength, e.g., like sand. Dry sand is cohesionless and therefore tends to slough and collapse during or soon after penetration by tunneling. Soils with low water-holding capacity are best against penetration by plant roots. Roots are discouraged from further downward intrusion upon encountering a layer that is not only initially dry but also incapable of storing much water, even on a temporary basis. Free-draining, coarse granular soils are most effective.

Gravel has the combined characteristics of very low water-holding capacity and low cohesive strength and is often ideal as a biobarrier against plants and most animals. However, the large voids present in narrowly graded gravel provide no resistance to penetration by insects. Also, these open voids facilitate piping and, therefore, a buried gravel layer needs to be protected by a filter layer located above (See FILTER LAYER). Fortunately, insect activity seems to be restricted to a depth of no more than about 2 meters, and therefore protection from insect activity may be achieved by manipulation of the depth of the barrier layer or thickness of the total cover. Depths substantially less than 2 meters may be adequate in some areas.

A gravel layer situated at the ground surface is capable of serving a dual role as biobarrier and as surface armor (See RESISTANT LAYER). Other resistant layers should similarly deter animals and plants. In contrast, the hydraulic barrier is seldom effective doubling as biobarrier also. Roots may preferentially tap the moisture of a fine-grained hydraulic barrier and in the process, disrupt it. Burrowing animals may also degrade the barrier by tunneling since the moist fine-grained soil is supportive of small tunnels. Occasional, serious penetrations are suspected with synthetic membranes but the experience base is sketchy and inconclusive.

The most attractive alternative to using a biobarrier in the cover system is through repairs and maintenance incorporated in long-term care. Damage to the cover and exposure of the hazardous waste by invaders needs separate attention in the maintenance program. Provisions for repairs may assume greater importance when the cover system includes no biobarrier.

DRAINAGE LAYER

The function of a drainage layer is to convey water or gas laterally and the layer must have a high permeability. This basic requirement usually dictates that the drainage layer be composed of narrowly graded granular soil such as sand. Suitable sand is almost always readily available. Drainage layers should generally satisfy filter criteria (See FILTER LAYER) to avoid susceptibility to plugging. Actually, drainage layers and filter layers are quite similar, and the specifications offered in Appendix A differ only in the details.

Ground freezing temporarily blocks the effectiveness of drainage layers. This phenomenon can be very serious in highway systems, and drainage in subbases may need to be positioned near the ground surface to minimize delays in drainage (34) during thaw. Fortunately, the resultant high pore pressure and pumping from traffic is minor at most in cover systems, and the drainage layer is usually positioned high anyway in order to remove water blocked by the barrier layer (Designs III and IV in Figure 14).

Drainage layers are occasionally supplemented with features such as pipes to facilitate the lateral movement and removal of water or gas. Clearly, the lateral movement is more efficiently accomplished where the average flow path is measured in feet rather than tens of feet. Supplementary features for improving the drainage function are identified and discussed in Section 5.

FILTER LAYER

A filter layer of soil or synthetic fabric serves to prevent downward migration of fine particles with percolating water. Migration of particles is to be expected in soils containing or having access to appreciable open void space. Thus, just about any soil layer, highly porous or not, situated over a porous disposal unit is potentially vulnerable to this process. Drainage layers and biobarriers with their characteristic large and abundant voids are particularly susceptible to participating in the migration process in combination with a finer soil layer above. Where movement is concentrated in discrete pathways such as along fractures, the process is known as piping.

The filter with its intermediate pore sizes provides a framework for favorable bridging action. The water continues downward, but the particles are retained in the small pores of the filter. The process eventually stops as the accumulated particles bridge across the miniature pathways. A filter as thin as 2.5 centimeters can be effective in road beds (6), but constraints of cover construction probably dictate a thickness at least 10 centimeters and probably more. The use of a filter layer in a cover system was first proposed seven years ago (2). Subsequent experience is insufficient to confirm effectiveness, but it can be said confidently that any effect should mostly be on the beneficial side, i.e., a filter layer offers extra assurance and should not introduce new problems into the system. One possible exception, however, comes in capillary effects. A soil filter interposed between coarse- and fine-grained soils may decrease the boundary's effectiveness as a capillary barrier. Filter fabrics may circumvent this possible problem.

Soil

Criteria for granular filter soil are generally recognized, although there is some variability in detail (35). These criteria are also applicable to designing filters around buried drainage pipes. A key Corps of Engineers criterion for stability is

$$\frac{\text{15-percent size of filter soil}}{\text{85-percent of finer soil}} \leq 5$$

A modifying criterion applicable to CL and CH soils only permits the 15-percent size of the first filter soil to be as great as 0.4 millimeter (Figure 24).

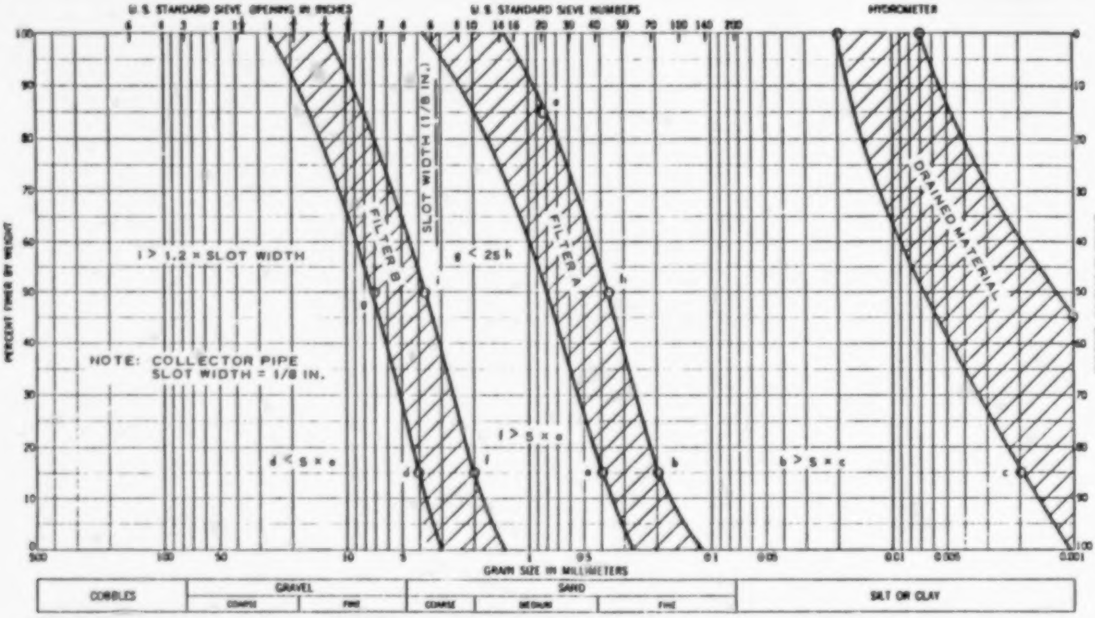


Figure 24. Illustration of the design of a graded (double) filter.

Gap-graded soils require special attention. For gap grading in the finer (protected) soil, the filter design considers the finer components only. Gap grading should be avoided in the filter soil itself, i.e., the grain-size curve should resemble those in Figure 24 in shape. Also, note in that figure the implications of dealing with ranges of sizes represented by a band rather than a single curve.

Fabric

The use of synthetic fabrics in solid waste management has been reviewed elsewhere (36). Fabrics are increasingly being substituted for granular soil layers in earthwork construction despite the disadvantage of high cost and disagreements about cost effectiveness (6). Unfortunately, the limited past experience still leaves open the question of service life which is a major concern in waste management. The effectiveness of fabric filters as well as soil filters may be decreased over a long period of time by physical deterioration or by plugging from biological and chemical deposits. This problem is probably much more serious where the filter surrounds a drainage pipe than in the case where the filter is a layer extending across the entire cover system, since percolation and reactants and products are more concentrated in the first instance.

Synthetic fabrics are vulnerable to damage by large subsidence, but they may serve to bridge across small subsidence holes and preserve cover integrity for a long period. The consequence of the preservation of voids beneath an apparently intact cover is one of the many aspects that need careful consideration during design. Such bridging can conceivably be favorable in some cases, but since the condition is only quasistable, it may only postpone and intensify a long-term problem.

Corps of Engineers criteria for filter cloth are based on the equivalent opening size (EOS) and percent open area. Woven filter cloths generally are available in the range of sizes between the No. 100 and No. 30 sieves. Nonwoven cloths range smaller than the No. 40 with coefficients of permeability ranging from about 0.01 to 0.9 centimeters/second.[1] The following selection criteria are most useful with woven cloth:

a. Filter cloth adjacent to granular soil containing 50 percent or less by weight of minus No. 200 materials should have a ratio of

$$\frac{\text{85-percent size of soil}}{\text{opening size of EOS sieve}} \geq 1$$

and should have an open area not to exceed 36 percent.

b. Filter cloths adjacent to all other types of soil should have an EOS no larger than the openings in the No. 70 sieve (0.0083 inch), and an open area not to exceed 10 percent.

c. To reduce the chance of clogging, no cloth should be specified with an open area less than 4 percent and/or an EOS of less than the No. 100 sieve (0.0059 inch). It is preferable to specify a cloth with openings as large as allowable to permit drainage and prevent clogging.

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[1] ASTM D4491, "Test Method for Water Permeability of Geotextiles by Permittivity" was approved by ASTM in 1985.

BUFFER LAYER AND FOUNDATION

A buffer layer in this document is any layer not functioning in one of the specific ways above. Among the several miscellaneous functions of buffer layers are the following:

a. Protect another layer during construction.

b. Serve as a foundation or base for construction.

c. Merge downward into backfill soil.

d. Distribute load.

e. Distribute deformation (such as settlement).

Each function may have its own requirements, but most requirements for a buffer layer are much less stringent than for those layers discussed above.

Nonselect soil is usually adequate and often present on site. For the protection of synthetic membranes less than 30 mils in thickness, it is essential that the soil be fine and free of pebbles and clods exceeding 3/8 inch in diameter that would threaten to puncture the membrane (37). Thick membranes may be able to sustain grain indentations without damage, but the risks should be carefully evaluated in consultation with the manufacturer or authority familiar with the characteristics of the membrane. Finally, the extra effort to achieve uniformity in material is worth while in providing stability to the layers above. More discussion on confirming uniformity and firmness is found under Proof Rolling (Special Methods, SECTION 6).

It is usually appropriate to distinguish the foundation apart from other buffer layer types. Cover systems are vulnerable to settlement and other processes originating in the waste cell below. Accordingly, the foundation is a key transitional zone between the cover system and the waste cell acting to dampen out or distribute the more seriously adverse effects. One should distinguish this specific usage of the term "foundation" from a more general usage found in the specifications in Appendix A. There, it has been necessary to describe also other "foundation" conditions immediately below a course or lift to be constructed and in some cases above the subgrade of the cover system. Thus, in Figure 13, Course 1 is part of the foundation of Course 2, and Course 2 is part of Course 3's foundation; yet the foundation of the cover system as a whole lies immediately below the indicated subgrade.

MONOLAYER DESIGN

A cover composed of a single layer is an option that might be considered under special conditions of material type and climate, particularly in arid regions where the downward penetration of water from the surface may be limited to only a few meters (See HYDROLOGY, SECTION 2). Very little water reaches the disposal unit, and the small amount that does has little adverse impact. A single-layer, thick cover will be sufficient for this situation. The other common condition favoring a single-layer cover is an abundant supply of clay-rich soil from which to construct the cap. Again, the soil cover will need to be of sufficiently great thickness. Note however that such a design would not satisfy RCRA requirements for new sites.

An important attribute of a single-layer cover besides low initial cost is its relatively simple maintenance. Subsidence holes or erosion gullies can be patched by the addition of more of the same soil. Ordinarily, however, some consideration would be given to modifications that would prevent a recurrence. A special application of a single-layer cover might be in its use at waste storage facilities such as described under DESIGN LIFE (SECTION 2) wherein requirements of longevity are largely relaxed.

SECTION 5

CONFIGURATIONAL DESIGN

Configurational design is intended to encompass all aspects of design of cover other than the stratification of a typical increment, i.e., the areal design factors as opposed to the vertical design (SECTION 4) in the vertical dimension alone. The average slope, topographic details, and drainage system probably constitute the most important among such areal factors.

In a large measure the same design methods and attitudes suggested in Sections 3 and 4 apply here also. However, the importance of testing and test results is less in regard to configurational design. The emphasis is on modifications and additions to the simple vertical design appropriate for the anticipated complexities of surface topography and size and geometrical arrangement of disposal units. Expected consequences of the character of the solid waste must also be anticipated and incorporated at this stage.

AREAL SIZE

The size of the cover is determined by the size and arrangement of disposal units. Covers for areal landfills may be quite extensive. Some flexibility may be available in trench burial where the disposal units are separated by partitions of undisturbed ground. The options are to cover individual disposal units separately or to cover the assemblage of disposal units in its entirety. The second option will require that an intermediate cover be placed as each disposal unit is filled. Otherwise, hazardous waste would be exposed or insufficiently covered over a period of years between the first unit and the last unit of the facility. It is also feasible to proceed in a stepwise manner wherein the final cover is completed over individual units or cells with subsequent steps following in which intervening areas are completed. This construction of the cover in several steps is probably not feasible for systems of more than two layers since it would be difficult to mesh the layers of the cover system from area to area.

The designer must also establish the amount of overlap beyond the outer edge of the disposal unit. Some sort of protective fringe will be necessary to block infiltration around the edge of the disposal unit or assemblage of disposal units. A reasonable rule of thumb might be sufficient guidance; for example the cover might be prescribed to extend at least ten feet beyond the outer edge of the cell liner. Ordinarily it would be preferable to have a width based on specific considerations of the site such as the vulnerability at the edge to water infiltration into particularly permeable layers in the site media near the ground surface. A feature addressing this concern is illustrated generally in Figure 25, but note that the unlined cell was for LLRW and is not suitable for RCRA needs.

SLOPE STABILITY

Inclined portions of the cover may be susceptible to instability from lateral movement. Areal landfills raised well above adjacent ground are most vulnerable. Vertical movement may also occur and be manifested as damaging differential settlement. This deterioration is separate from erosion, though also concentrated on the slope. Frequently erosion and instability occur together, and costly repairs and modifications are needed. Careful analysis of conditions usually reveals potential problems, which can be avoided by modification of the design. Generally and as a rough rule of thumb, any slope over 25 percent and height over 50 feet deserves careful consideration for analysis of stability.

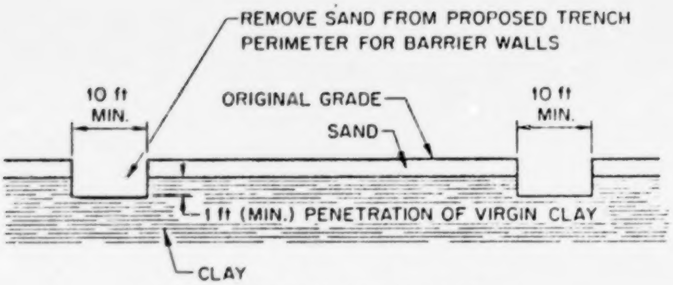
To prevent instability, the cover designer usually concentrates on drainage of water and strengthening of the system (See Slope Stability, SECTION 3). Instability is often localized, particularly on steep slopes, and therefore the stabilizing features should also be localized. One of the most effective ways of improving stability in a questionable slope is by construction of a strong embankment for retaining any weak materials (Figure 8). Such an embankment can constitute part of the cover or be part of a retaining system. The CECOS hazardous waste facility in Niagara Falls, New York, makes use of such a stable embankment for lateral support and as a foundation for the synthetic liner (Figure 26). The stable embankment circumvents the problem of unstable cover; however, some disposal space is sacrificed.

Both surface and subsurface drainage features are used to remove water from soil and stabilize a threatening saturated condition. Transient saturation may follow thawing of frozen soil or may result from accumulation of infiltrating water impeded by a hydraulic barrier. Buried pipe drains and toe drains in the form of French drains are optional supplemental features. A major consideration in using subsurface drainage features is the extent of long-termed deterioration such as from piping or plugging. Surface drainage ditches have the advantage of being directly observable during long-term service, and maintenance is simple and inexpensive.

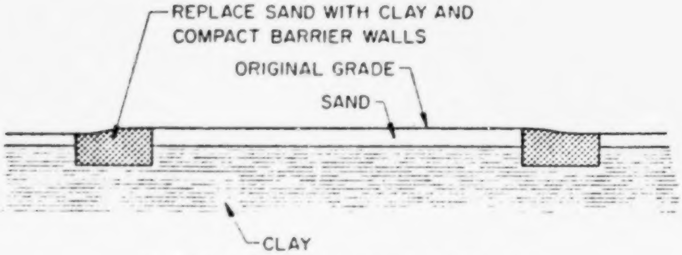
An option for strengthening slopes is the addition of a berm to give additional mass resistance against sliding or flowing. Berms may also provide favorable drainage where composed of coarse, granular material, particularly riprap. Such a berm with large open voids keeps the level of transient saturation at a depressed position where it will not threaten stability.

DRAINAGE SYSTEM

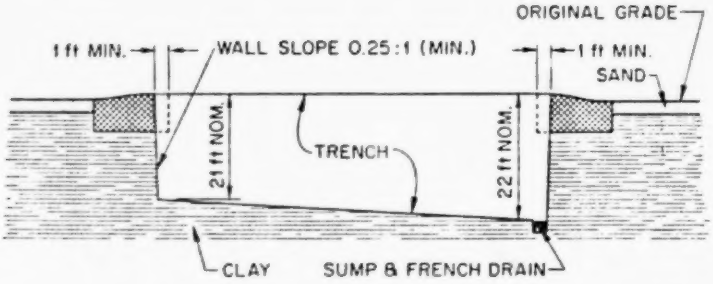
The cover system must be augmented with a well-conceived drainage system to facilitate rapid conveyance of rainwater and meltwater to basins or channels located off the cover. This emphasis follows from the general axiom that it is best to remove as much water as possible before it can infiltrate. Accordingly the topography and the ditch and channel designs are high-priority items in the total system. Short direct channels have a decided advantage in


REMOVE SAND FROM PROPOSED TRENCH PERIMETER FOR BARRIER WALLS
10 ft MIN.
ORIGINAL GRADE
10 ft MIN.
SAND
1 ft (MIN.) PENETRATION OF VIRGIN CLAY
CLAY

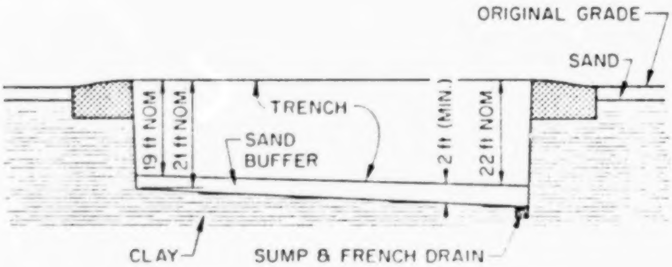
PHASE I TRENCH PREPARATION


REPLACE SAND WITH CLAY AND COMPACT BARRIER WALLS
ORIGINAL GRADE
SAND
CLAY

PHASE II TRENCH PREPARATION


ORIGINAL GRADE
1 ft MIN.
WALL SLOPE 0.25:1 (MIN.)
1 ft MIN.
SAND
21 ft NOM.
TRENCH
22 ft NOM.
CLAY
SUMP & FRENCH DRAIN

PHASE III TRENCH EXCAVATION


ORIGINAL GRADE
SAND
19 ft NOM.
21 ft NOM.
TRENCH
SAND BUFFER
2 ft (MIN.)
22 ft NOM.
CLAY
SUMP & FRENCH DRAIN

PHASE IV ADDITION OF SAND BUFFER

Figure 25. Edge feature in LLRW trenches at Barnwell LLRW facility (38).

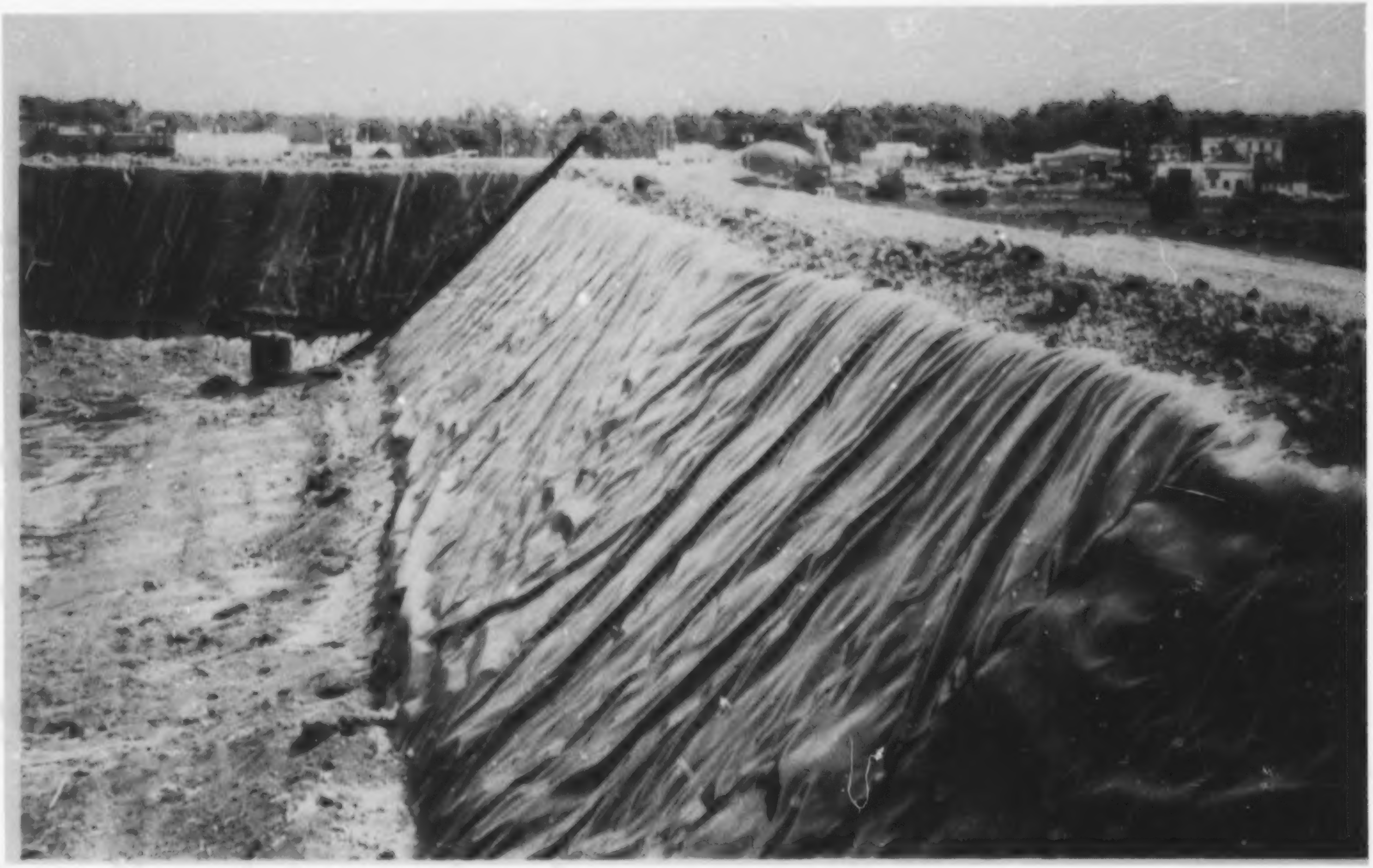


Figure 26. Confining embankment at CECOS facility.

conveying water off site. Similarly steep slopes are also the most expeditious routes, but the sacrifice made in greater erosion has to be carefully weighed.

Certain strategies may be available early in design where flexibility remains in the choice of type of disposal unit. In Figure 27 one arrangement of disposal trenches provides the opportunity to develop short direct paths for runoff to trunk channels located on undisturbed ground between trenches. Experience at Sheffield, Illinois, indicates that even the undisturbed ground admits infiltration from low spots (40). The same general pattern of direct runoff channels to a system of trunk channels can be considered for large areal fills; however, the trunk channels may be vulnerable to long-term deterioration, particularly from settlement. It may also be necessary to provide liners for the runoff channels to prevent infiltration from the channels themselves. A criterion for liner clay is given in Figure 20 and the explanatory text. Liners are also discussed along with other structures and features of drainage under SPECIAL FEATURES AND STRUCTURES.

EROSION MITIGANTS

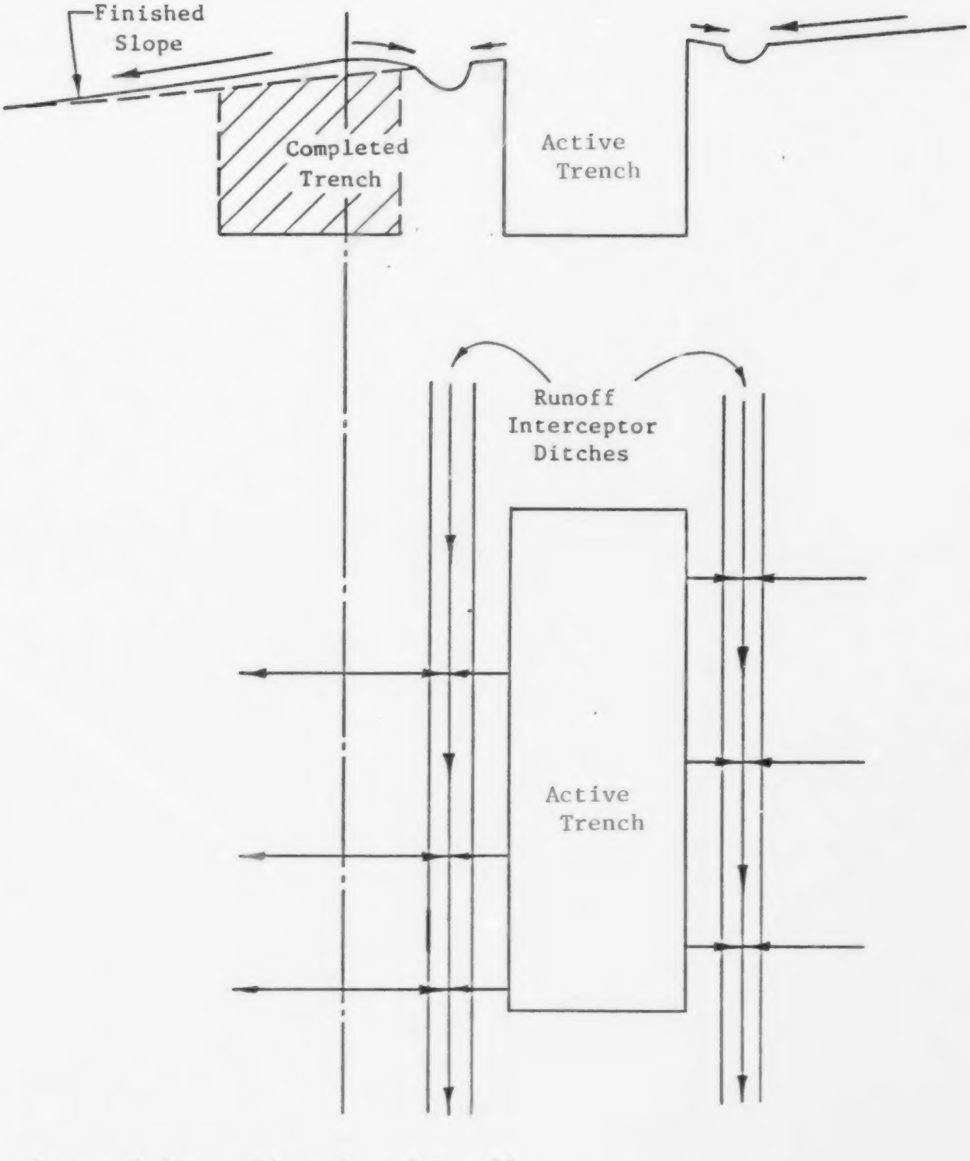
The designer usually faces a dilemma in choosing measures to minimize erosion. The best techniques against field erosion promote infiltration and thus may create an even more serious problem for the cover over hazardous waste. A carefully designed and effective layered cover system addresses both problems together by limiting most infiltration to the upper layers only (see SECTION 4).

Establishment of durable vegetation is often the most effective method of erosion control despite the dilemma noted above. Details of vegetating a cover are provided in Section 8. Conservation techniques such as terracing should be considered also. Ridges are created to serve as obstructions for reducing flow velocity and erosion. Application of gravel surfacing along gullies in cover systems has been used as a repair procedure (40). Similarly gravel can be placed along potential erosion lines to resist development of gullies before the fact.

More elaborate protection against erosion is justified where major runoff channels are present, particularly along the edge of the cover system. Possible infringement of channels of this nature is generally avoided in siting or designing the disposal units. Occasionally, the channel may be diverted. Wherever the problem exists or wherever extra protection is wanted, the designer may opt for a layer of cobbly, washed stone or riprap. Stone material must meet criteria of weight and size gradation adequate to resist the velocity surge of design storm runoff. Other techniques of armoring may also be considered (Figure 28).

SETTLEMENT CONTINGENCY

Provisions should be made for handling settlement on the basis of a very careful appraisal of the amount and nature of eventual cumulative settlement (see Settlement, SECTION 3). Understanding the process centered within the disposal unit allows the rate and total settlement to be estimated and


Finished Slope
Completed Trench
Active Trench
Runoff Interceptor Ditches
Active Trench

Arrows Indicate Direction of Runoff

Figure 27. Trunk and lateral channels in surface drainage (39).

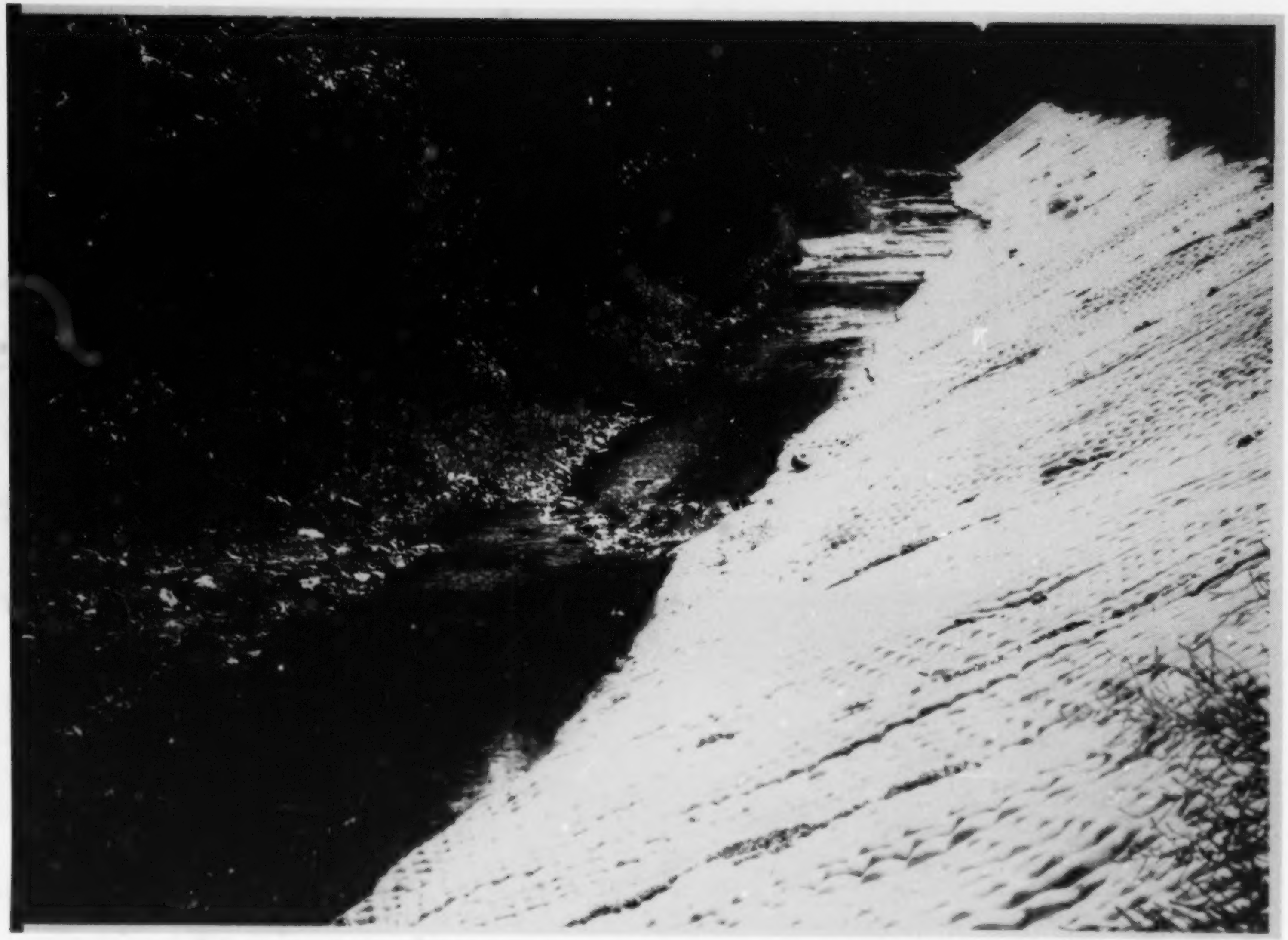
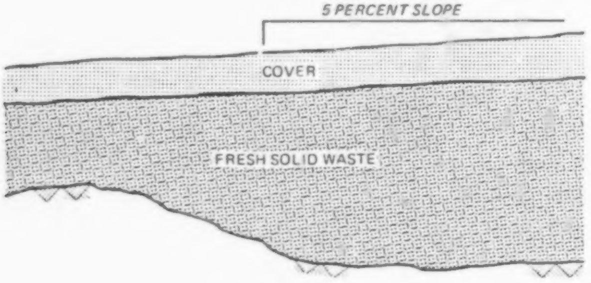


Figure 28. Cement-filled mat for erosion protection at Hamilton landfill.

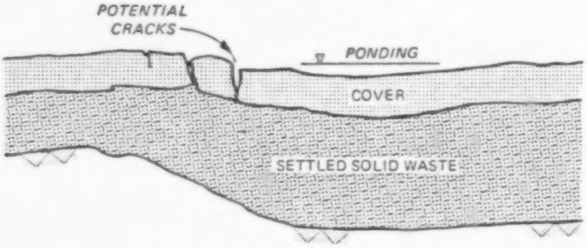
facilitates the plans for long-term monitoring and the planning for maintenance and possible repair.

The appropriate design provisions may amount to thickening the cover or its important elements such as the soil hydraulic barrier. Thickening provides a tolerance for preservation of the continuity of the barrier or cover as illustrated in Figure 29. Settlement may be even more serious for a synthetic membrane since the thin sheet may tear or be punctured and become ineffective.

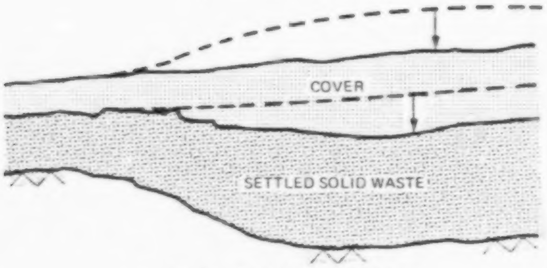
Evenly distributed settlement may be accommodated in advance by increasing the inclination on the ground surface so that ground slope after settlement is still properly directed and adequate to achieve runoff as planned.


5 PERCENT SLOPE
COVER
FRESH SOLID WASTE

a. BEFORE SETTLEMENT


POTENTIAL CRACKS
PONDING
COVER
SETTLED SOLID WASTE

b. AFTER SETTLEMENT


COVER
SETTLED SOLID WASTE

c. THICKENED COVER BEFORE AND AFTER SETTLEMENT

Figure 29. Thickened cover for tolerance of settlement damage.

The problems of anticipating settlement and counteracting its effect are most complex where the cover crosses an assemblage of separate disposal cells with undisturbed soil or embankments between (Figure 30). The contrasting behaviors of such disparate materials, especially where superimposed as in the figure, will accentuate the differential settlement. Unmanageable combinations should be anticipated and avoided in order to head off serious problems. Cover at the boundary of trenches or distinct waste cells is vulnerable to damage. Not only is differential settlement concentrated at that interface, but also there is a tendency for voids to be left there during the backfilling operation. This vulnerability of trench boundaries can be observed from experience at Sheffield. Figure 31 illustrates the preferential concentration of subsidence holes along the side of a covered trench.

BOUNDARIES

The lateral boundaries of the cover system should be distinguished as a separate part or feature so that they do not become a liability through neglect. The importance of the outer edge of the cover system can be made more understandable when the edge is viewed as a feature keying the cover system into the liner or some important part of the site media. This viewpoint is superior to considering the boundary of the cover system as a safe place to terminate it. Figure 32 shows one simple edge feature, a vertical clay barrier wall connecting the hydraulic barrier in the cover to a clay stratum in the site media. An overlapping or welding of cover membrane across liner membrane is more typical of the edge of RCRA facilities; Figure 33 is an actual design for a RCRA facility in the midwest. Also note the fabric serving to drain water blocked by the cover membrane.

A boundary will also be necessary where two or more cover systems are used on a single hazardous waste facility. Attention must be focused then on the interface between systems. The problem is clarified by considering one promising combination of two cover systems (Figure 34). The designer may choose to supplement his use of a vegetated soil on flat areas by using gravel at the surface on slopes. One would anticipate some long-term deterioration of the lateral boundary between these two cover systems, particularly where the vegetated cover lies upslope of the graveled cover. Fine-grained particles in the vegetated soil will continue to be washed into the relatively open space of the gravel. Both cover systems will suffer a diminution of their effectiveness along the boundary.

Careful attention by a knowledgeable engineer should produce options for reducing long-term deterioration. Figure 35 shows a feature that has been used upslope of riprap. Another option recommended for consideration is the placement of an inexpensive fabric along the interface to block the migration of fines (Figure 34). The ultimate deterioration of the fabric should be sufficiently delayed (over a period of tens of years) to permit a degree of self-stabilization, as by the establishment of permanent vegetation. Even in a deteriorated condition, the fabric should continue to function favorably for an indefinite period.

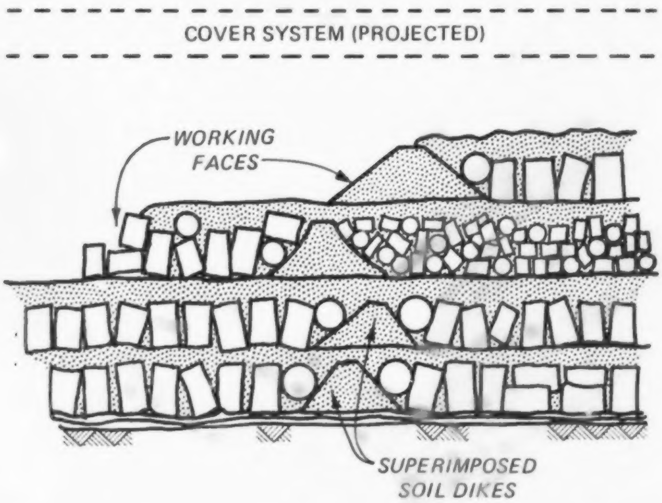

COVER SYSTEM (PROJECTED)
WORKING FACES
SUPERIMPOSED SOIL DIKES

Figure 30. Extreme contrasting conditions possible within cover foundation (waste cells).

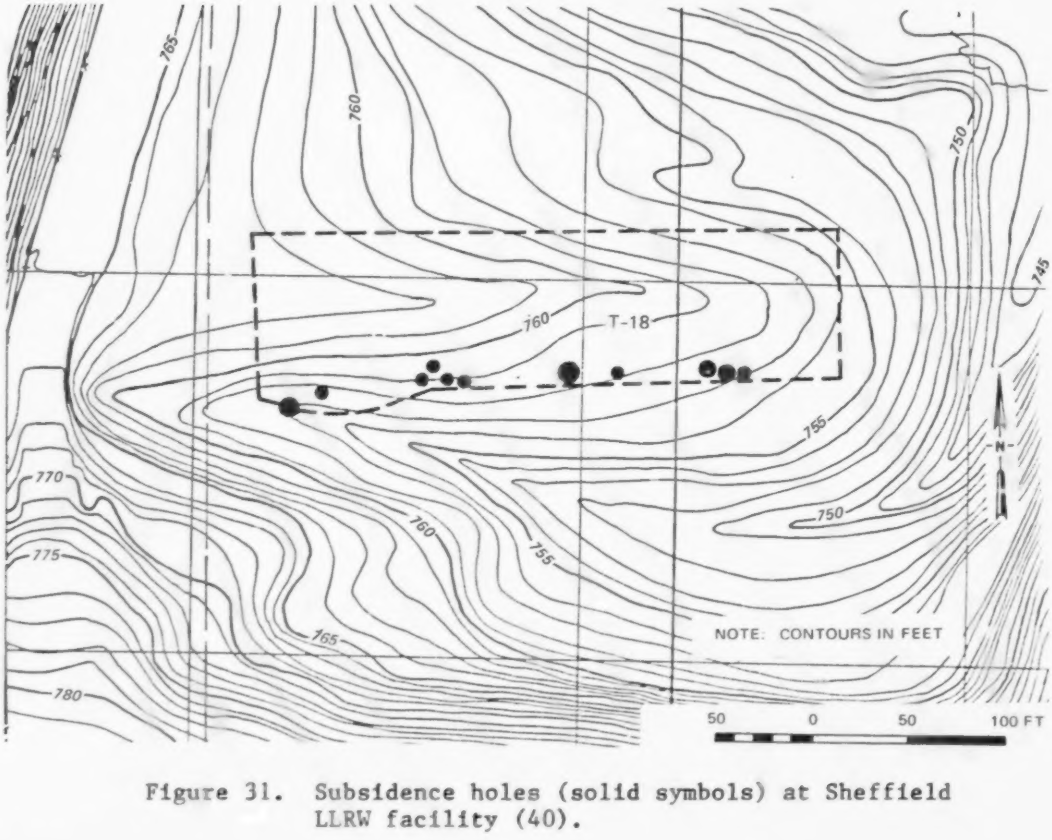

765
760
750
745
760
T-18
755
N
770
775
760
755
750
765
780
NOTE: CONTOURS IN FEET
50
0
50
100 FT

Figure 31. Subsidence holes (solid symbols) at Sheffield LLRW facility (40).

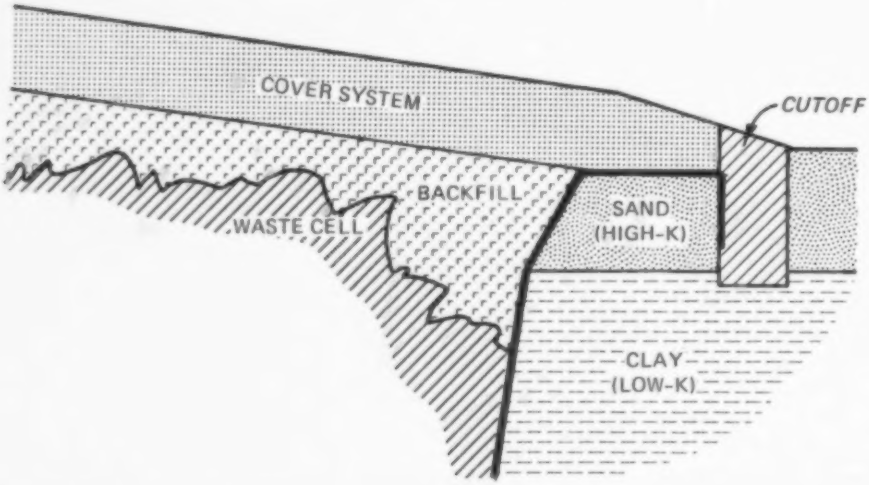

COVER SYSTEM
CUTOFF
BACKFILL
WASTE CELL
SAND
(HIGH-K)
CLAY
(LOW-K)

Figure 32. Clay wall connecting cover into low-permeability stratum.

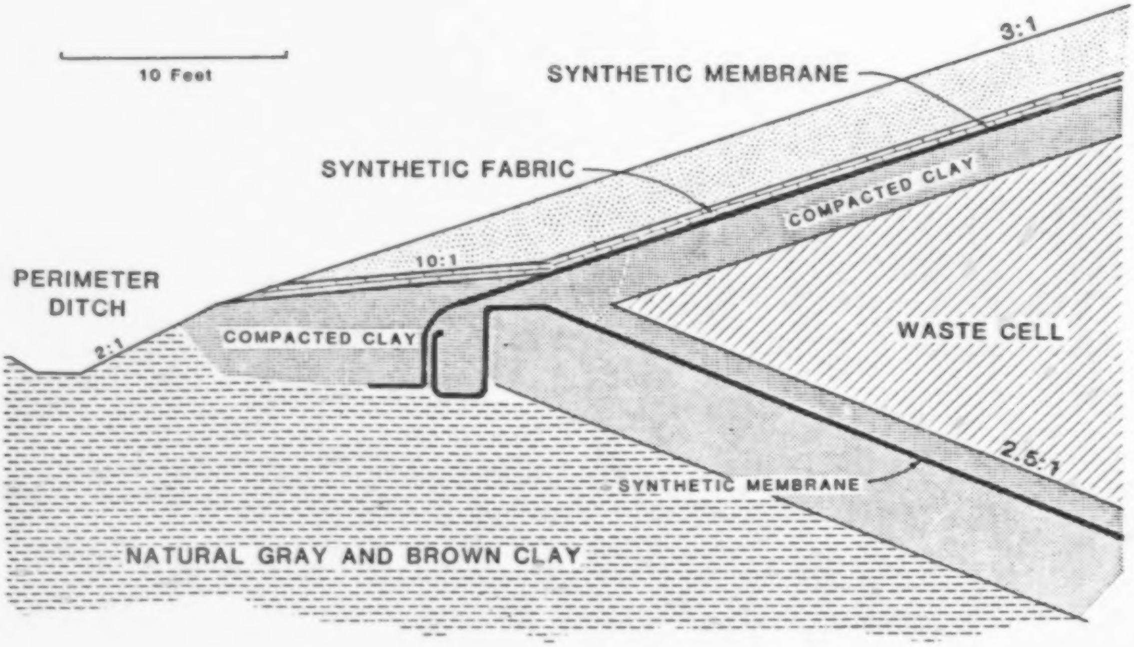

10 Feet
3:1
SYNTHETIC MEMBRANE
SYNTHETIC FABRIC
COMPACTED CLAY
10:1
PERIMETER
DITCH
2:1
COMPACTED CLAY
WASTE CELL
2.5:1
SYNTHETIC MEMBRANE
NATURAL GRAY AND BROWN CLAY

Figure 33. Design for overlap of membrane at edge of waste cell.

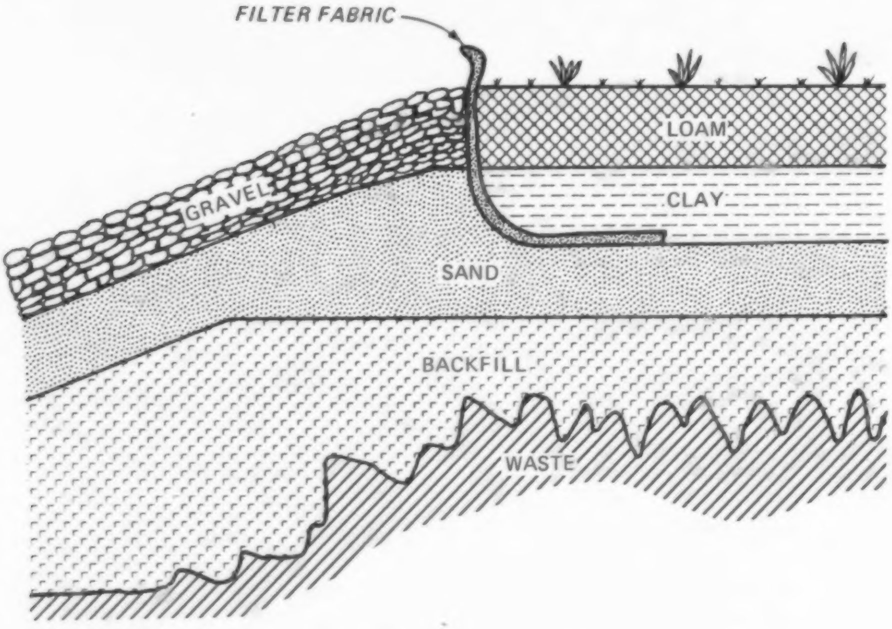

FILTER FABRIC
LOAM
CLAY
GRAVEL
SAND
BACKFILL
WASTE

Figure 34. Boundary feature between two cover sections.

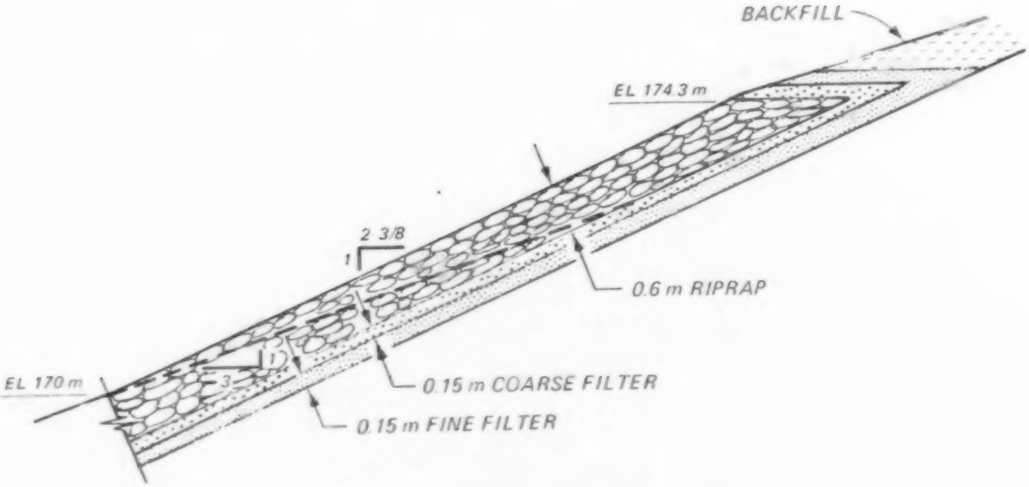

BACKFILL
EL 174.3 m
2 3/8
1
0.6 m RIPRAP
EL 170 m
1
3
0.15 m COARSE FILTER
0.15 m FINE FILTER

Figure 35. Filter feature separating riprap from adjacent material upslope and at depth (Welland Channel Relocation, St. Lawrence Seaway Authority, Canada).

SPECIAL FEATURES AND STRUCTURES

It is sometimes advantageous to consider special features as a separate part of the design. Some redundancies may arise since special features may also be considered more directly in addressing certain cover functions such as drainage. Consideration of special features listed in Table 17 is recommended regardless of redundancy.

Surface drainage channels function to maximize runoff without appreciable erosion. Infiltration is most effectively reduced or prevented by a channel lining of concrete, clay, asphalt, or synthetic material. Grassed waterways and channels are much less effective sometimes because the appreciable infiltration which they facilitate works contrary to the overall design. A major problem with all surface runoff channels comes in assuring that longitudinal continuity and gradient are maintained. General or differential settlements discussed under SETTLEMENT CONTINGENCY can disrupt a channel and make it ineffective.

TABLE 17. SPECIAL FEATURES IN COVER DESIGNS

Culverts

Grade stabilizers:

- Chute spillways
- Drop spillways
- Pipe spillways
- Drop inlets

Liners:

- Grassed waterway
- Clay liner
- Gravel liner
- Hard liner

Floodways and diversions

Gas vents

Subdrains (e.g., plastic pipe)

Sump and collectors

Slurry walls

French drains

Monitoring ports or access

Pads

Tree wells and islands

Sediment ponds

Subsurface water drainage features can serve in a capacity similar to surface drainage features. In fact, the areal pattern or layout of one system may partly superimpose on the other. In both cases, gravity drainage to linear depressions is the essential process. Subsurface drainage features may consist of linear gravel bodies filling trenches. Perforated drain pipes may facilitate the drainage process. Such subdrains are routinely installed along highway bases where drainage problems are anticipated (42). Subsurface drainage features usually require a filter wrap to prevent clogging, which otherwise may abort a long service life. Where a choice is necessary, a surface drainage system is usually preferable to a subsurface drainage system. Key features are easier to monitor, evaluate, and repair.

Gas vents and drains are somewhat similar to water drains (Figure 36) but tend to drain upward rather than downward and may be situated relatively high. A feature preventing access of surface water must be included. Most RCRA facilities generate very little gas.

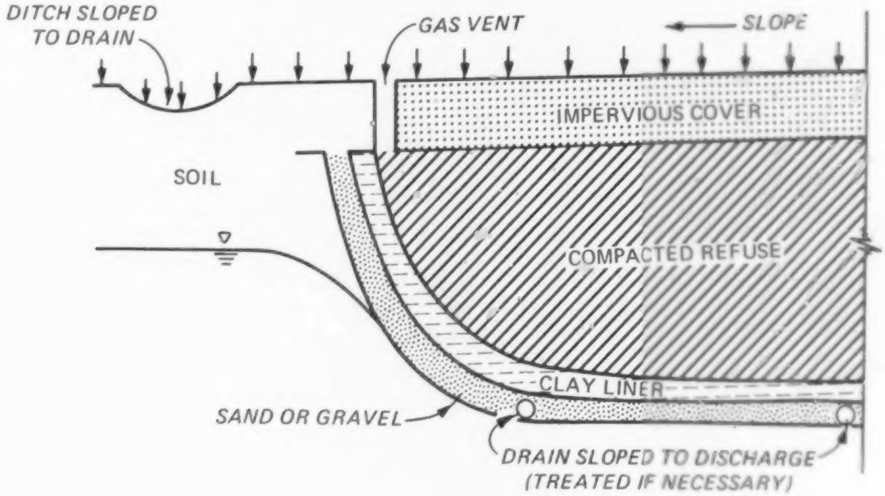


Figure 36. Gas venting trench (43).

French drains and cutoff walls are special large features that are available for consideration in modifying a pattern of subsurface flow. French drains are commonly used as toe drains to facilitate drainage of subsurface water and improve slope stability. A major French drain has been used effectively at Oak Ridge (Figure 37). Cutoff walls of soil of low permeability can block and divert percolating water as a part of the drainage system. Subsurface water might be blocked by such a feature and diverted to a subsurface drain (Figure 38). Walls may be constructed using slurry (44) or by compacting soil in a trench or by construction as an increment of the overall system at the time of cover placement. Another possible form of cutoff wall is shown in Figure 25 where the wall keys the cover system into a suitable stratum in the site media.

Other special features that conceivably will be needed at hazardous waste facilities are two-dimensional pads for vents, shelters, and shrubs or trees. The cover designer will have to anticipate these eventual needs and provide the necessary technical details for proper integration into the cover system. Emplacement after construction of the cover may be acceptable or maybe even

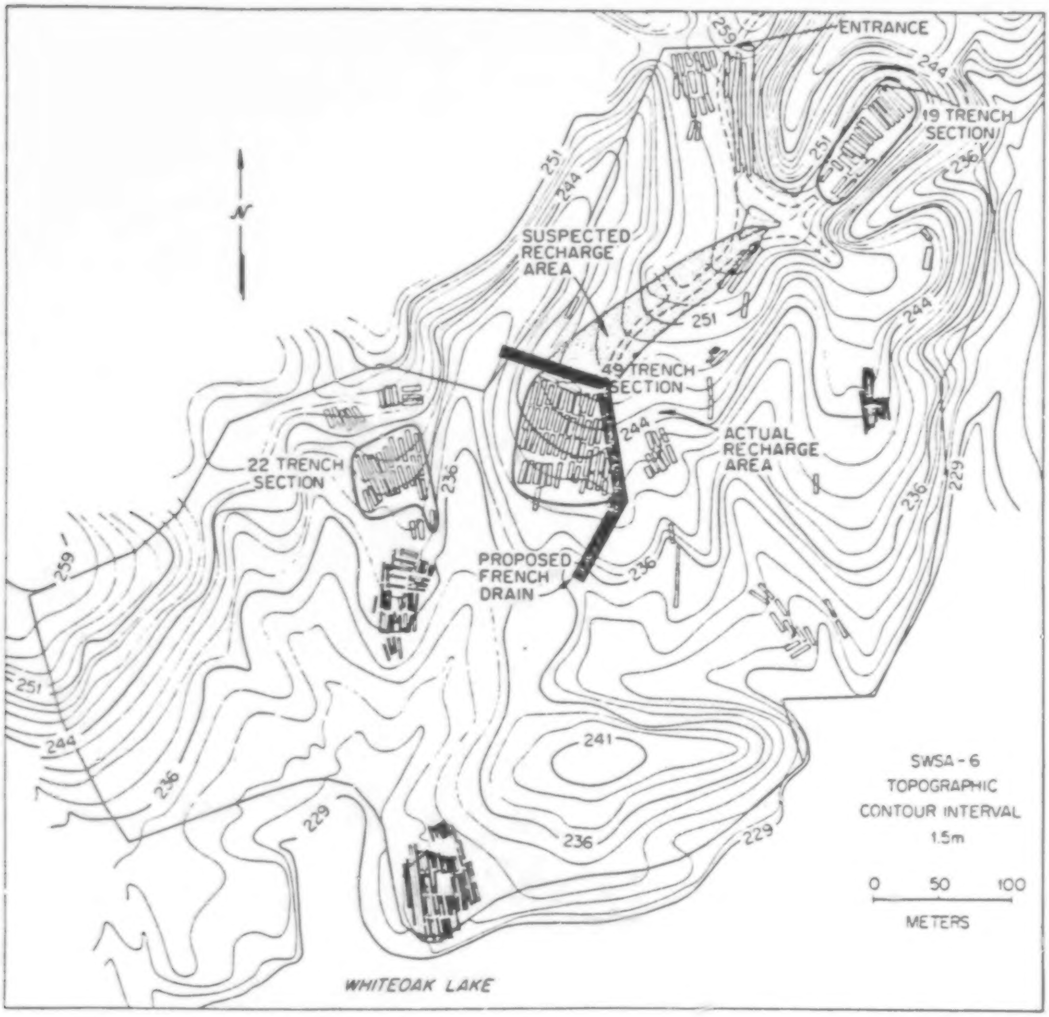
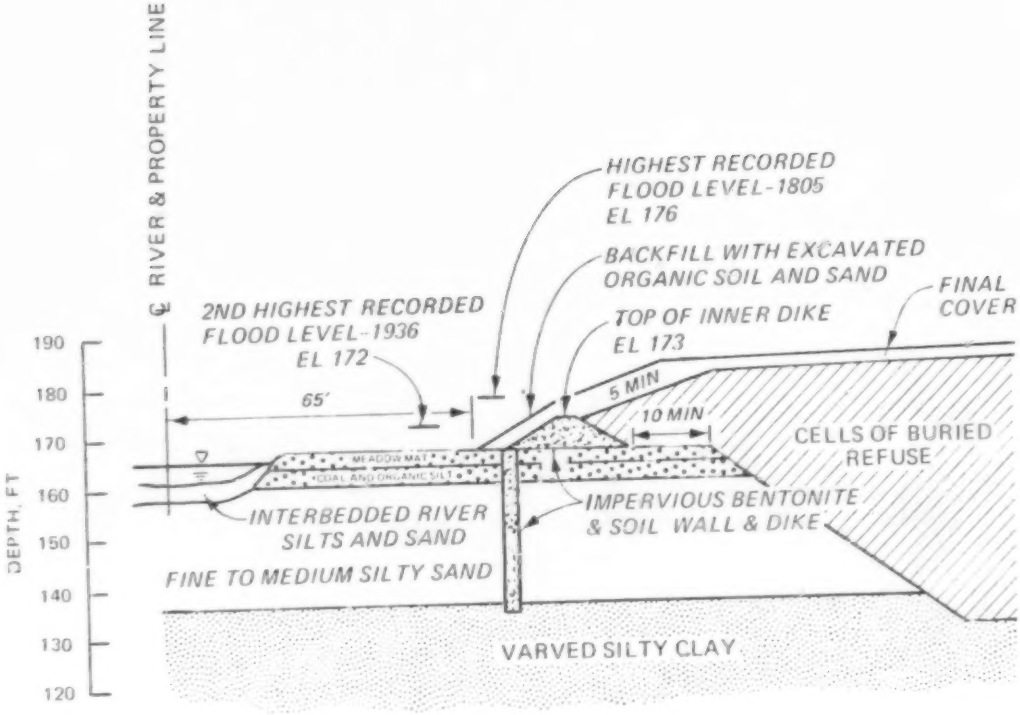

ENTRANCE
19 TRENCH SECTION
SUSPECTED RECHARGE AREA
49 TRENCH SECTION
ACTUAL RECHARGE AREA
22 TRENCH SECTION
PROPOSED FRENCH DRAIN
N
259
251
244
236
229
241
SWSA-6
TOPOGRAPHIC
CONTOUR INTERVAL
1.5m
0 50 100
METERS
WHITEOAK LAKE

Figure 37. French drain for controlling seepage at Oak Ridge (from Oak Ridge National Laboratory).

preferable in some cases, but elsewhere, and probably more commonly, such retrofitting will introduce discontinuities and weaknesses into the system. It is common practice in establishing monitoring holes in undisturbed media to provide a concrete collar with wide flange at the ground surface to prevent leakage of surface water down the borehole. The installation of such a monitoring feature through a cover and into the waste disposal unit will be considerably more complex if much settlement is possible. Some sort of telescoping collar might be necessary to accommodate the ultimate settlement.



℄ RIVER & PROPERTY LINE
HIGHEST RECORDED FLOOD LEVEL-1805 EL 176
BACKFILL WITH EXCAVATED ORGANIC SOIL AND SAND
FINAL COVER
2ND HIGHEST RECORDED FLOOD LEVEL-1936 EL 172
TOP OF INNER DIKE EL 173
190
180
170
160
150
140
130
120
DEPTH, FT
65'
5 MIN
10 MIN
CELLS OF BURIED REFUSE
MEADOW MAT
COAL AND ORGANIC SILT
INTERBEDDED RIVER SILTS AND SAND
IMPERVIOUS BENTONITE & SOIL WALL & DIKE
FINE TO MEDIUM SILTY SAND
VARVED SILTY CLAY

Figure 38. Cutoff wall and dike for excluding seepage (modified from Reference 45).

NONTECHNICAL CONSIDERATIONS

Nontechnical aspects that may affect the design of the cover system are concerned with aesthetics, convenience, work safeguards, and the eventual use of the covered area. Careful consideration should be directed to the mid-term and ultimate conditions at the site. If the site is to be returned to a natural-like condition, there may be a benefit in contouring to a natural configuration. On the other hand, it may be advantageous to form the surface in an orderly and unnatural configuration attracting attention perpetually into the future.

Where some beneficial use of the land is anticipated, that use should be manifested in the cover design. Conceivably a disposal facility should serve another purpose after closure and termination of license, e.g., for storage of equipment and goods. The requirements and use of a storage area then would have to be generally compatible with the cover design and its expected operation, and vice versa. The need for large flat areas for parking vehicles or for storing pallets would substantially affect the design of the cover. Again, the focusing on future use and continued serviceability of the cover should head off problems otherwise resulting from uncertainty about requirements decades in the future.

Final considerations falling between technical and nontechnical come in the ever-present concerns for job safety and for general environmental safeguards.

SECTION 6

COVER CONSTRUCTION

Workable cover designs must be implemented through appropriate construction techniques. Important tasks in construction are excavation or borrow, material preparation, placement, compaction, and installation of special features. Guidance on accomplishing these and other tasks is provided in the following paragraphs.

EQUIPMENT SELECTION

The choice of equipment for construction of the cover system is sometimes intentionally limited to units readily available on site and therefore appearing to be most cost effective. Otherwise, the contractor may select or adapt equipment for each task from a great variety. Major construction tasks with corresponding equipment are as follows (Figure 39):

Task	Equipment
Material excavation, mixing, and loading	scraper, loader, dozer
Material transportation	truck, scraper, front loader
Layer placement	grader, scraper, crane, dozer, front loader
Layer compaction	compactor, dozer

In selection of equipment for various jobs or combinations of jobs, heavy reliance is occasionally placed on descriptions from equipment manufacturers. It thus remains for the designer as well as reviewing officials to recognize and separate intrinsic characteristics among promotional claims.

Where the covering is accomplished by the site operator, there will be a strong inclination to use equipment already available. For some routine operations, these basic units often include medium-size dozer, front loader, fork lift, and crane. A major task then becomes the utilization of these units in the most effective manner.

The excavating, mixing, and loading operations in the schedule of constructing a cover are usually conducted on a small scale in comparison to

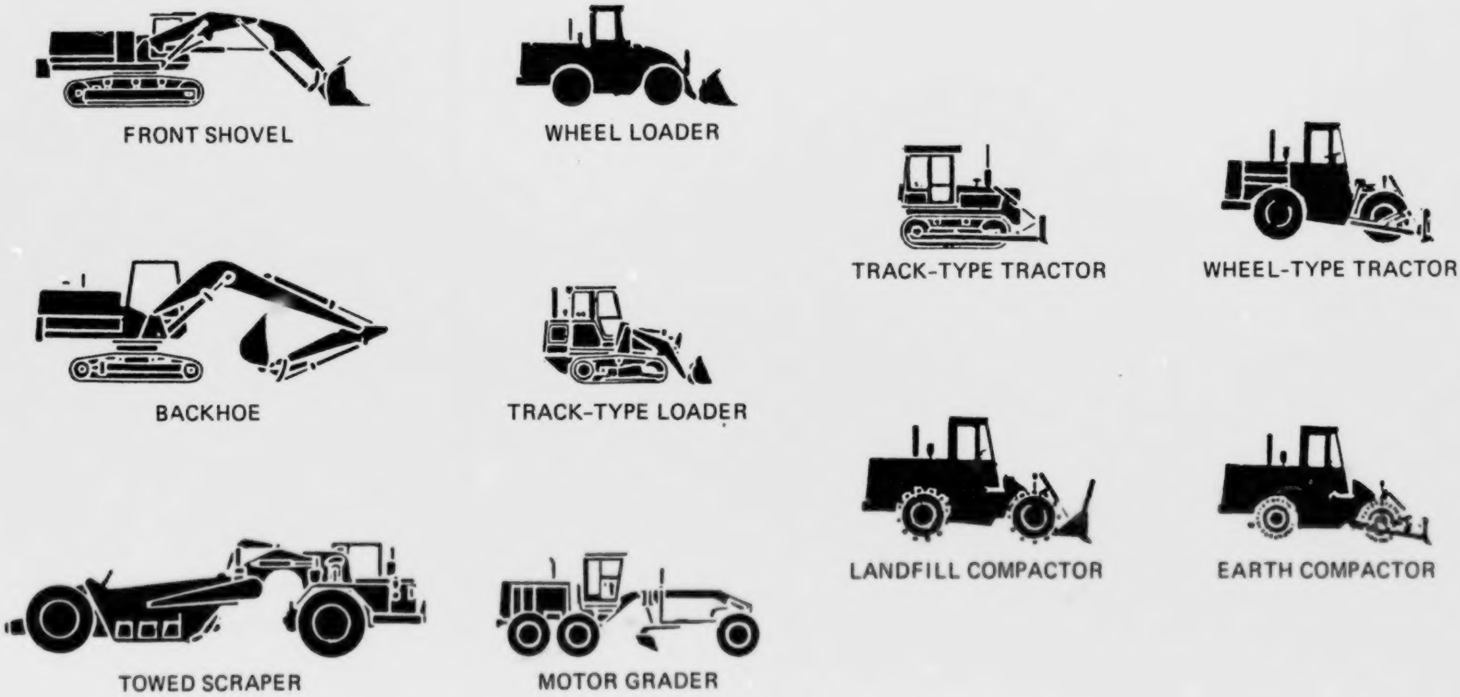

FRONT SHOVEL
WHEEL LOADER
TRACK-TYPE TRACTOR
WHEEL-TYPE TRACTOR
BACKHOE
TRACK-TYPE LOADER
LANDFILL COMPACTOR
EARTH COMPACTOR
TOWED SCRAPER
MOTOR GRADER

Figure 39. Construction equipment for waste disposal.

operations for large earthwork such as highways or dam embankments. This scale constraint tends to affect the selection and use of the equipment in turn. Specialized equipment for large-scale excavation such as large power shovels is not feasible on a cost-benefit basis. Versatile medium-size front loaders, can be used to excavate, mix, load, and even transport materials. The skillful contractor considers power, bucket size, and similar characteristics in determining the proper equipment.

Front loaders are particularly efficient on stockpiled material. An initial rough mixing may be achieved by alternating increments from component stockpiles in the process of loading. Mixing may also be accomplished by combining the component stockpiles with a dozer prior to loading. Mixing accomplished at the loading site, however, should be followed by additional mixing during placement of the soil in the cover system. A routine procedure will have to be established early in the initial operations or on a test section to ensure that components of a blended soil have not remained segregated here and there in the cover.

Transportation of soil from the source to the site of construction is accomplished by trucks or scrapers. Where public roads are involved, trucks will be the only reasonable means. Frequently, a stockpile adjacent to the disposal units will be established, so that the vehicle from offsite is not necessarily the same one that carries the material to final placement. One advantage of an intermediate stockpile is the opportunity for additional mixing.

A major criterion for proper placement of a layer is preservation of the condition of the layer below. This may dictate that the equipment has light contact pressure such as achieved with wide dozer tracks. Wheeled vehicles tend to rut. A technique that helps to protect the layer below is utilization of a front loader or other extendable unit to minimize crossings on the completed layer by limiting the equipment to the area well back on the incomplete layer.

A crane (Figure 40) is ideal for remotely depositing soil in a position for spreading. Then only the spreading equipment and laborers traverse the cover. Cranes are probably limited by their reach to trench operations, but they may already be available for utility in handling waste and in backfilling. Backfilling around waste is very effectively accomplished with a crane, and where this backfill merges upward to a foundation for the cover system, placement with the crane may be a key task of the construction of a cover system. Dozers are ideal for spreading and are commonly preferred.

Equipment available for compacting is diverse but generally falls into categories of smooth rollers, tamping rollers, impact rollers, and vibratory rollers (Table 18). The sheepsfoot roller is a tamping roller that has received extensive use and universal acceptance in embankment construction, but its use in cover compaction needs to be preceded by an evaluation of effects on layers. The steel feet produce kneading action in the compacted layer and may disturb the layer below as well. Obviously, a thin barrier layer or membrane may be damaged by excessive disturbance. Sheepsfoot rollers may be ideal for compacting the backfill and foundation below the subgrade

TABLE 18. COMPACTION EQUIPMENT AND METHODS FOR GENERAL EARTHWORK

Equipment type	Applicability	Compacted thickness, in.	Passes*	Dimensions and weight*
Sheepsfoot rollers	Fine-grained soils or dirty coarse-grained soils	6	4-8	Foot contact area 5 to 14 in.^{2} Foot contact pressures 50 to 500 psi
Rubber tire rollers	Clean, coarse-grained soils	10	3-5	Inflation pressures of 60 to 80 psi. Wheel load 18,000 to 25,000 lb
	Fine-grained soils or well-graded, dirty coarse-grained soils	6-8	4-6	Inflation pressures exceeding 65 psi for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use large tires at 40 to 50 psi
Smooth wheel rollers	Well graded sand-gravel mixtures	8-12	4	Tandem-type rollers for base course or subgrade. 10 to 15 ton weight; 300 to 500 lb per lineal inch of width of rear roller
	Fine-grained soils other than embankments	6-8	5	3-wheel roller weighing 5 to 6 tons for soils of low plasticity to 10 tons for soils of high plasticity
Vibrating baseplate compactors	Coarse-grained soils	8-10	3	Single pads and plates should weigh no less than 200 lb
Crawler tractor	Coarse-grained soils	10-12	3-4	No smaller than D8 tractor with blade, 34,500 lb weight, for high compaction

*For compaction to 95 to 100% Standard Proctor maximum density.

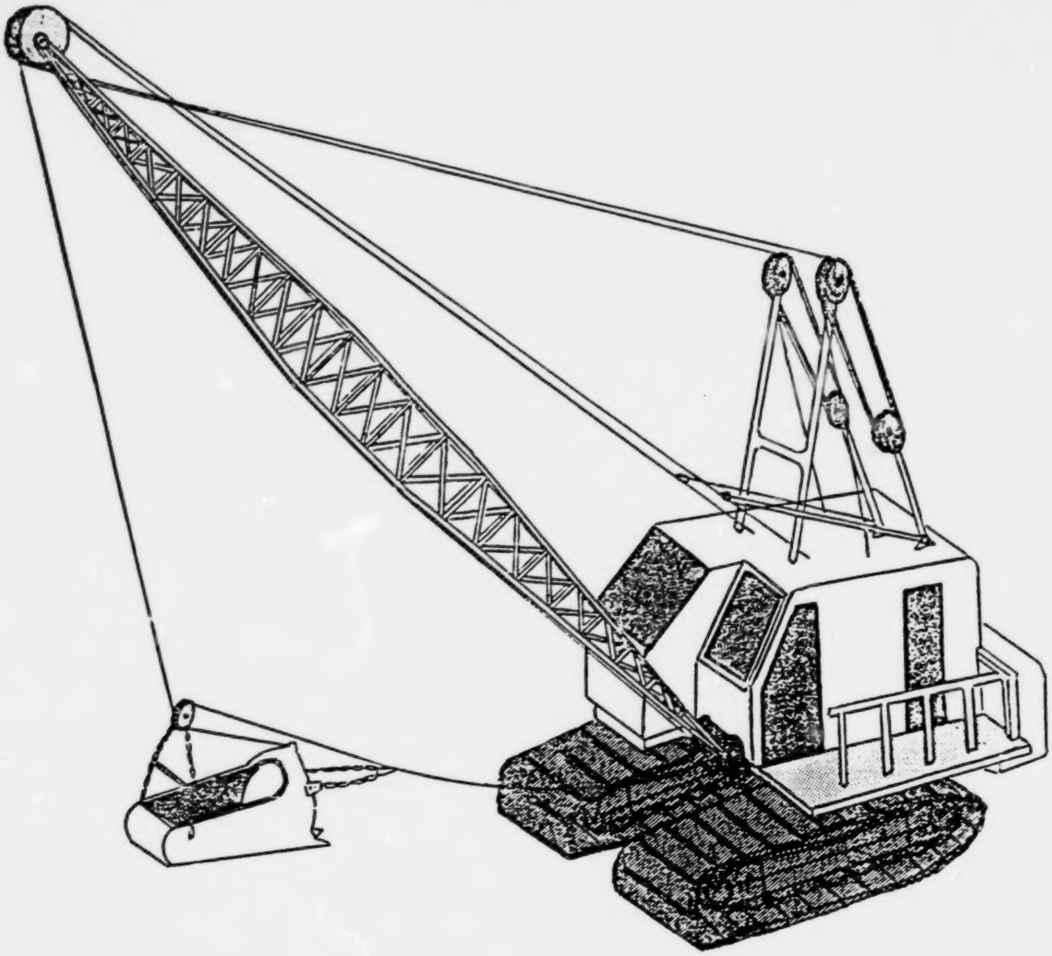


Figure 40. Crane operating as a dragline.

(Figure 13). It is recommended that compactors designed for compacting waste be avoided unless careful consideration and validation by test section demonstration have been accomplished.

Smooth rollers and tire rollers appear to have advantages in construction of layered covers because they cause less disturbance other than densification. The simplest rollers are towed by tractor; more advanced models are self-propelled. Weight is increased or decreased with ballast. Smooth-wheel vibratory rollers are preferred in general earthwork for cohesionless (granular) soils.

Numerous types of tractor-drawn equipment are available for scarifying the surface to improve bonding with the next lift or layer above. Methods are discussed under Interface Treatment. Rakes with short teeth may be custom-made, or a type of farm harrow may be purchased. The depth of penetration should receive considerable attention to ensure that the benefits of previous compaction are not lost.

Water spreaders are needed for increasing the water content in the process of compaction. A tank truck with distributors for spreading water evenly may already be available on the site for dust control. Alternatively, a contractor might have or be able to lease one.

Special tools and machines are available for establishing vegetation on a cover. By contracting the vegetation work, the operator circumvents the question of equipment needs, and this option will be favored by some. Harrows loosen soils at the ground surface. Fertilizer and other additives are incorporated by disking or tilling or can be spread as a liquid. Hydroseeders accomplish the fertilizing, seeding, and mulching at one time, and this equipment is preferred by many contractors specializing in vegetation of disturbed lands. However, some specialists feel that better results are achieved where seeding is accomplished separately with drill seeders. Similarly, equipment for crimping or punching straw mulch into soil gives a more durable surface protection in the usual application. The thickness of the vegetative soil layer and sensitivity of underlying courses may constrain the choice of some equipment.

MATERIAL PREPARATION

Blending

In circumstances where two or more materials must be blended, several options are available.[1] When the materials occur as strata one above the other in the same borrow pit, excavation by shovel can sometimes blend them together with little extra effort or expense. Construction control in this case will require maintaining the height of cut to obtain the necessary proportions of each type of material and to assure that the two materials are intermixed. Satisfactory mixing can be accomplished with dragline excavation, but greater attention must be given to this operation since the tendency will be to remove material in horizontal cuts. Several special types of excavating equipment have been developed such as wheel excavators and belt loaders, which have excellent capabilities for blending from vertical cuts.

When scraper excavation is used, the difficulty of securing a satisfactory mixture is increased, and it is often necessary to provide supplemental mixing on the fill by disking or blading. Excavation is performed by making a slanting cut across the different types of soil, and care must be exercised to secure the proper proportions of each type in each scraper load.

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[1] This discussion on blending is in part from the Bureau of Reclamation (29) and the Department of the Navy.

Considerations of cost limit the procedure for blending soils from separate sources. One of the soils may be stockpiled upon the other so that loader cuts can be made across the two. Soils may be placed in thin layers on the fill and then mixed by blading or similar manipulation before being compacted. The correct proportion in terms of depth of the fine soil is usually placed first, then the correct depth of coarse soil. The blending then follows. In this way, any remnant of the lower soil unaffected by blending consists of the finer material rather than being coarse material more vulnerable to percolation. Mixing plants are the ultimate though most expensive option to obtain an intimate mixture.

The specifications for placing soil included in Appendix B illustrate how three methods of mixing have been described in contracts, in this case for construction of granular subbase for flexible road pavement.

Modification

Soil may also be modified[1] with relatively minor amounts of additives such as lime, cement, asphalt, and salts. Bentonite is commonly considered for improving the effectiveness of hydraulic barriers. Generally, the use of modified soils may be considered in lieu of replacing poor soils with selected material from a distant source. For example, the use of lime to moderate the expansive characteristics of a clay soil from immediately available borrow may be satisfactory and more economical than importing special material.

Conventional methods are usually used to place and compact modified soil, but special equipment and procedures are sometimes needed for mixing the additive. Special tests of the modified soil may be required to verify the amount of additive, and visual observations should be made to ensure that the additive is uniformly distributed. Construction control testing of placement water and density is also usually required (SECTION 7). After initial calibration, periodic checks during construction will ensure satisfactory results.

For soil-cement and soil-bentonite mixtures, a stationary mixing plant is usually required of either batch type or continuous feed pugmill type. Control over mixing time, positive interlocking of cement and soil flow, and controls for accurately proportioning the soils, cement, and water should be incorporated into the plant operation.

Trucks for transporting the soil-cement mixture should have tight, clean, smooth beds and protective covers. The spreader must produce a smooth, uniform, loose lift of the required width and thickness. The lifts are usually placed horizontally; however, a working lift as steep as 1 vertical on 8 horizontal has sometimes been permitted to increase the working width. The maximum time for hauling and spreading is usually specified as 30 minutes so that compaction must be closely coordinated with preceding tasks. See SOIL COMPACTION for guidance on compacting soil-cement mixtures.

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[1] This discussion on modification is from the Bureau of Reclamation (29).

SOIL PLACEMENT

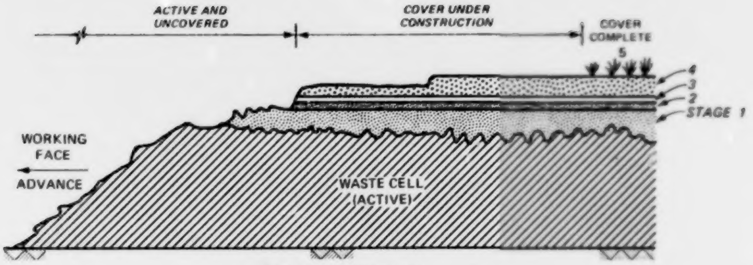
The primary objective of placement operations is to distribute the soil evenly and to the proper thickness. A relationship between the bulk thickness as placed initially and the final thickness after compaction should be established early in the operation so that compacted thickness will not be found later to be deficient. This relationship is ideally determined in a test section (See TEST SECTION).

Secondary objectives of a carefully managed placement operation are to preserve the integrity of the layers situated below and to complete the homogenization or mixing process initiated in the borrow pit or at the stockpile (Also see Blending). Preservation of the integrity of the layer situated immediately below is especially critical. A relatively thin hydraulic barrier can be seriously damaged by cracking or shearing if traversed excessively by equipment constructing the layer above. It has been stated that placement of soil to protect a membrane, a related procedure from general earthwork construction, requires hand manual labor (5). A fine mesh geogrid placed on the vulnerable layer and removed later may alleviate some traffic disturbance and prevent contamination with debris (6).

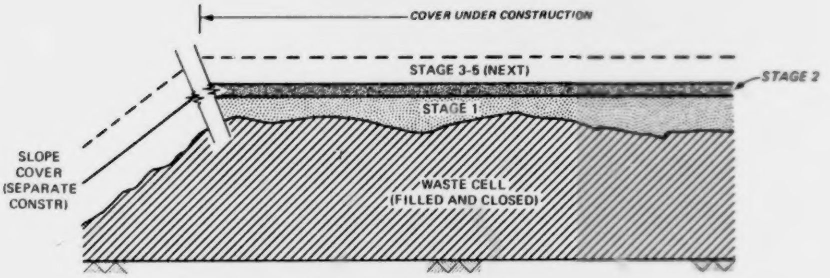
One basic method of soil placement is by dozing from a pile at the edge of the cover or in incremental piles across the cover. The sequence for such an operation starts with placement in piles distributed linearly along the edge. The soil is then spread inward normal to the edge to form the proper bulked (precompaction) thickness. Then the next linear pile is deposited at the edge of the portion of the cover that is yet uncovered. Vehicles with broad wheel or track surfaces are most suitable in traversing the newly spread cover layer since they exert less ground pressure and are less likely to rut. Upon observation of rutting of sufficient depth to deform critical cover layers or foundation, a change in vehicle may be necessary. By careful planning, supervision, and inspection, the equipment passes across any portion of the cover can be kept to a minimum and reasonably uniform. Alternatively, these traverses may serve as a part of the compaction routine.

Where a crane is available, the layer material can be distributed in piles across the area. The approximate volumes needed to achieve the desired bulked thickness are distributed accordingly. This might facilitate the final spreading, which then would amount simply to smoothing out a hummocky surface of many separate piles.

It is anticipated that most cover systems will be completed in layer increments, and guidance above is so directed. However, the cover may also be completed in areal increments (Figure 41). Such areal subdivision may be necessitated by long time intervals of exposure between increments, or the plan may provide more efficient use of the equipment, personnel, and material flow. For example, a cover might be completed in long strips flanked on one side by the foundation of backfill and on the other side by the completed and seeded cover somewhat like strip mining of shallow coal. Such a procedure of construction in strips would usually present substantial difficulties in attaining layer continuity across the temporary boundaries of the strips. For covers of only one or two layers, this interfacing problem might be


ACTIVE AND UNCOVERED
COVER UNDER CONSTRUCTION
COVER COMPLETE
5
4
3
2
STAGE 1
WORKING FACE
ADVANCE
WASTE CELL (ACTIVE)

a. AREAL INCREMENTS


COVER UNDER CONSTRUCTION
STAGE 3-5 (NEXT)
STAGE 2
STAGE 1
SLOPE COVER (SEPARATE CONSTR)
WASTE CELL (FILLED AND CLOSED)

b. DELAYED PLACEMENT

Figure 41. Construction of cover in areal increments versus all at one time.

subordinate when compared with advantages of cost or efficiency inherent in the areal increment plan. A demonstration of feasibility in a test section would probably be essential (See TEST SECTION).

SOIL COMPACTION

Depending on design requirements, soil layers are constructed to one of the following conditions:

a. No special compaction--as for the vegetative layer.

b. Equipment-traversed--emphasis on routing the haulage and spreading equipment evenly.

c. Compacted--emphasis on special rolling to achieve compaction.

This section mostly describes the methods for c above. Note throughout the marked distinction between procedures for fine-grained soils and those for granular soils.

Compaction is usually described in terms of compacting equipment, water content, load applications, and density results. General equipment types are discussed under EQUIPMENT SELECTION. Because the compaction process involves a physical manipulation of a variable natural material, engineers depend heavily upon widely accepted procedures based on past experience.

Test Criteria

It is explained in this section and in Section 7 how tests are essential for predicting compaction results as well as for comparing field density achieved to that desired. Tables 11 and 19 list compaction tests along with other tests used in design and construction. Notice the distinction between the tables: design tests versus construction tests.

TABLE 19. CONSTRUCTION TEST METHODS

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
Water Content	ASTM D2216 ASTM D3017 AASHTO T217	(Oven dry) (Nuclear) (Calcium carbide)	
Unit Weight	ASTM D1556 ASTM D2167 ASTM D2922 ASTM D2937	(Sand cone) (Rubber balloon) (Nuclear) (Drive cylinder)	
Thickness	--	Linear measurement	Direct visual
Surface and Layer	--	Visual examination	Important; with or without proof rolling
Seam Integrity	-- --	(Air lance) (Vacuum box)	Direct visual
Resistance	ASTM D1558	Needle penetration	Also for water content
Permeability	ASTM D3385	Infiltration rate	Approximates permeability
	Desig. E-36	Shallow well permeability	Reference 29

Note: Design-oriented tests in Table 11 are sometimes needed also.
* ASTM: American Society for Testing and Materials
AASHTO: American Association of State Highway and Transportation Officials

Compaction decreases permeability and increases strength of soil as a result of the densification. The field compaction is planned from the results of laboratory compaction tests. In critical layers such as hydraulic barriers, the coefficient of permeability may be addressed directly, and accordingly, the density necessary to achieve the desired permeability can be explored and established by a series of permeability tests on specimens compacted to different densities.

The laboratory compaction procedure is intended to simulate the compactive effort anticipated in field construction (Figure 42). A standard 25-blow compaction test (Table 11) is used to simulate field compaction of fine-grained soils in routine foundations and embankments (Figure 43). Another "standard" compaction test may be preferred but, once selected, should remain the same for subsequent comparisons. Laboratory compaction is also reflective of some solid waste cover compaction, or it may be appropriate to adjust for lower compactive efforts. Five- and fifteen-blow tests are similar to compaction on municipal solid waste. Compaction tests are made on the soil at various water contents to establish a relation between water content and dry unit weight after compaction. Generally, five specimens should completely define the compaction relation.

Numerous procedural details are potentially important, making it essential that testing be conducted by experienced technicians or in certified laboratories. For example, it is sometimes important to store the prepared soil in an airtight container for a sufficient length of time to permit absorption of water (Also refer to ASTM D 698).

The results of compaction tests are presented in the form of a compaction curve on a plot of dry densities (dry unit weights) versus the corresponding water contents (Figure 43). The plotted points are represented with a smooth curve; for moist fine-grained soils, the curve approaches a parabolic form.

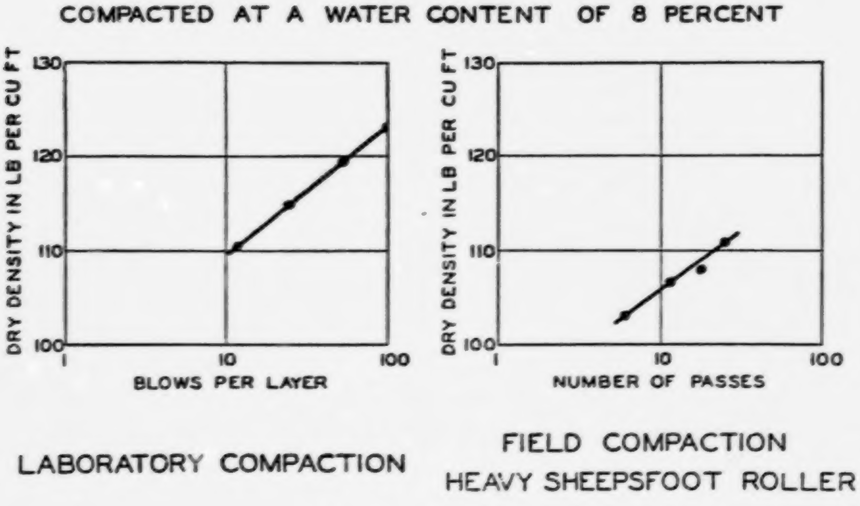


Figure 42. Similarity between compaction in lab and field.

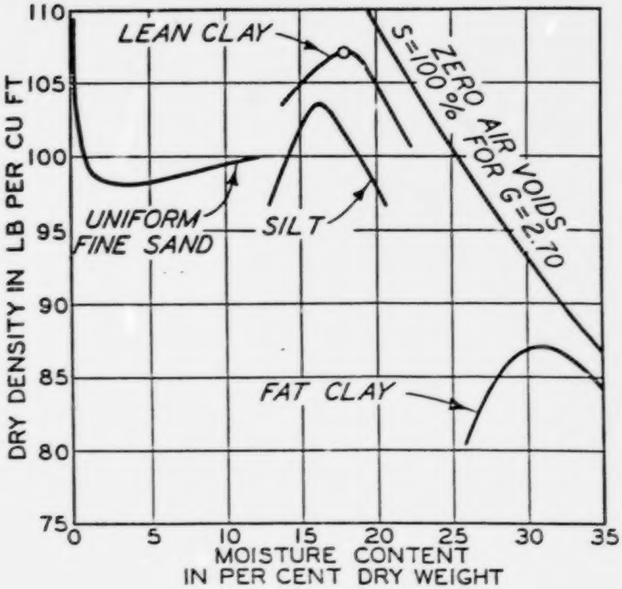


Figure 43. Results of standard compaction tests on sand and other soils.

The water content at the peak of the compaction curve is designated the optimum water content. The dry density of the soil at the optimum water content is the maximum dry density. The zero air void curve represents the dry density and water content of the soil when completely saturated with water.

Sand has a different response to compaction over a range of water contents (Figure 43). The degree of compactness of such cohesionless (granular) soils is sometimes expressed in simplified different terms as percent relative density. The lower limit corresponding to 0 percent relative density is obtained by pouring the soil loosely into the measuring container. The upper limit at 100 percent relative density is reached by tamping and shaking down to a minimum volume. Refer to Table 11 for the standard procedure.

Some geological materials respond to compaction atypically. Figure 43 shows that sand may exhibit no maximum on the compaction curve. The anomalous behaviors of some overconsolidated soils was mentioned under Geological Media (SECTION 2). Materials previously subjected to large natural overburden loads or to cementation have gained an additional increment of cohesive strength, but they may degrade and change during placement and compaction. Residual soils including extreme types such as lateritic soils may also be strengthened metastably. In any case, the testing for these soils should realistically reflect the planned compaction process in order to avoid misleading test results. It is partly for this reason that a different soil specimen is used for each compaction test point in standard practice rather than varying the water content on a repeat which may have degraded.

Water Content

Natural water content of soil often approaches the optimum for compaction; therefore, it may be unnecessary to modify the water content. Where compaction tests indicate, however, that the natural water content is not appropriate to satisfactory compaction, water may be added by sprinkling or subtracted by spreading to dry before using. Spreading and drying are expensive, and it may be advantageous to excavate and stockpile in fair weather and add water as appropriate later when used.

For fine-grained soils, field compaction sometimes achieves maximum density at a water content somewhat greater than optimum indicated by a comparable laboratory compaction test, and it is sometimes specified that departures from optimum water content be on the wet side. This departure has been shown to reduce permeability in the laboratory. Compaction on the dry side may be appropriate with swelling soils since the water imbibed later should promote further swelling and work against the formation of cracks (except at the ground surface). Field tests as described under TEST SECTION are suited to exploring such construction details. However, since the appropriate water content impacts on design, it would be best to resolve any question well before the start of construction.

One may estimate optimum water content by wetting fine-grained soil until a compact ball can be formed manually. No water should be squeezed out, and the soil should retain its dense structure after opening the fist. For pervious granular soil the conventional practice is to add water in abundance, but for cover layers positioned directly on the waste and below a synthetic membrane, a modification may be necessary to avoid wetting the waste cell below.

When large amounts of water are required, it may be more efficient to add most of it at the point of excavation with only supplemental sprinkling after the layer has been spread.[1] Mixing and curing after sprinkling may be required to produce a uniform water condition throughout the layer before compaction can proceed. Inspection of uniformity should be made by sampling the loose layer frequently just prior to compaction. Unless otherwise specified, optimum water requirements should be enforced even though the required density is obtained at other water conditions also. Adverse permeability properties may result if the placement water is too low, and adverse shear properties may result if too high. Therefore, the inspector should be prepared and authorized to require application or removal of water. Control of pervious granular soils includes visual inspection for free-draining characteristics and uniformity.

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[1] The discussion on inspection control in this and the next two paragraphs is largely from the Bureau of Reclamation (29).

The adequacy of the compaction and water additions is monitored by field density tests in conjunction with compaction control tests for clayey and silty soils, or relative density tests for pervious sand and gravel soils (Tables 11 and 19). Unless otherwise specified, the minimum acceptable density is 90 percent maximum density (by standard test) for the minus No. 4 fraction of clayey and silty soils and 70 percent relative density for the minus 3-inch fraction of pervious sand and gravel soils. With soils which are borderline, between fine-grained soils controlled by the compaction test and granular soils controlled by the relative density test, control may be based on the criterion which produces the higher unit weight.

Number of Passes

The energy input which determines the density achieved by the compacting process is increased by the number of passes of the equipment. Thus, while the soil density actually achieved is the determining criterion, the number of passes or coverages can be used as another parameter for estimating appropriate compaction provided water content is right. Figure 44 shows how a family of field compaction curves can be developed to quantify the effect of number of passes in terms of dry density. The strengthening effect of compaction, in terms of the California Bearing Ratio (CBR), is also illustrated. The compactor was a sheepsfoot roller, but similar compaction curves have been developed for dozers (2) and for a tire roller (Figure 45).

Table 18 shows the approximate number of passes for intermediate sizes of five types of compactors, i.e. appropriate for achieving 95 percent of maximum density as represented in a laboratory compaction test. The tabulated estimates may be viewed as a consensus among construction organizations in a very general way, but they should not be regarded as more than useful first approximations. Better estimates can be obtained from equipment manufacturers, past experience, or field tests.

The similarity in the number of passes necessary with a sheepsfoot roller and with a tire roller may be surprising in view of the fact that the two types are quite different from one another. A tire roller covers an area completely in one pass.[1] On the other hand, the sheepsfoot roller creates concentrations of stress only on the increments of area beneath the feet (Figure 46). Accordingly, numerous passes of a sheepsfoot roller are needed for a full coverage of an area. This contrast deserves little further consideration in view of the fact that the two types of rollers compact in different ways. The difference is illustrated dramatically in the next section where attention is focused on lift thickness.

The designer should always have an appreciation of the effect of increasing the number of passes since it is common in earthwork to specify a minimum number of passes within the specifications. Such prescriptive directions may

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[1] It is recommended that "pass" or any comparable term such as "coverage" be defined carefully, since meaning has varied in the past. Such past ambiguity has occasionally resulted in contract disputes in general earthwork.

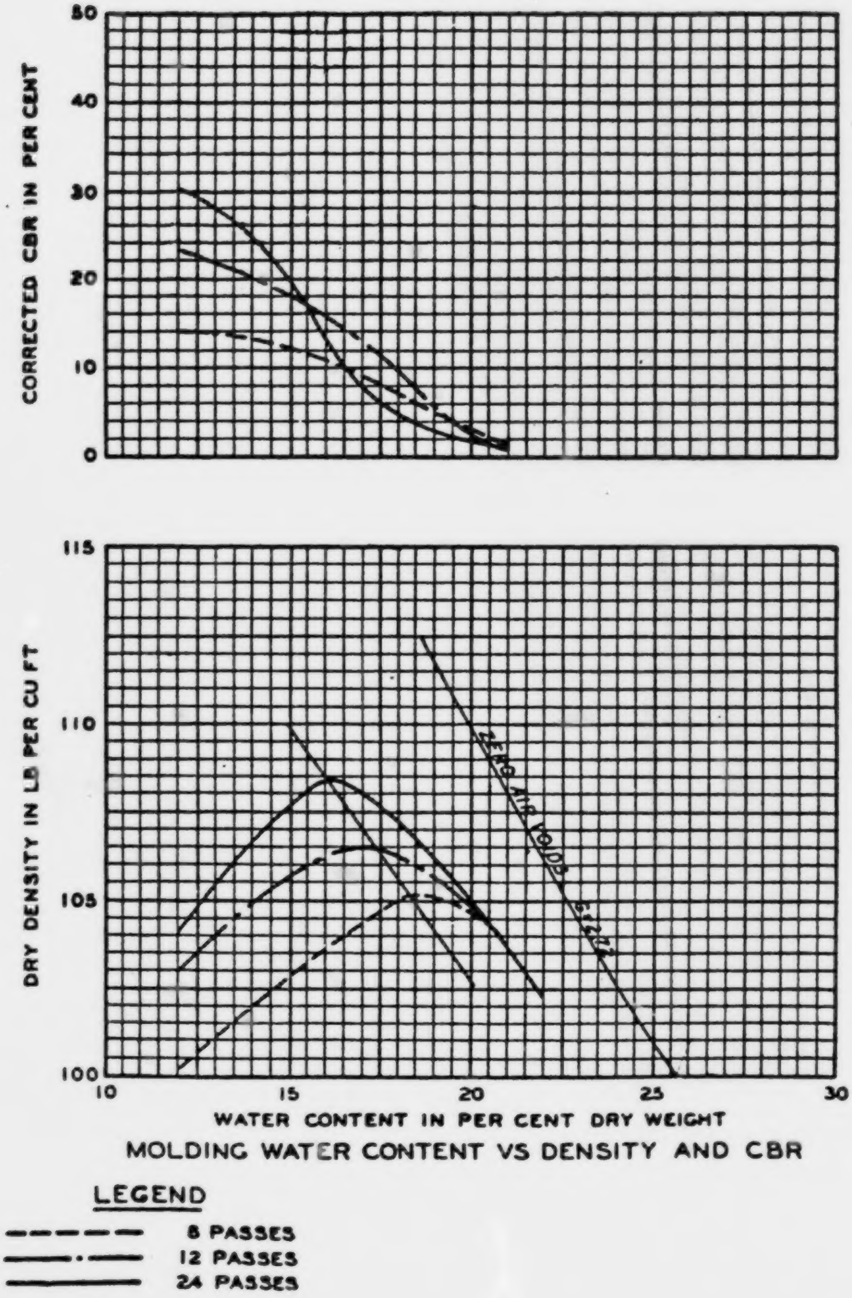
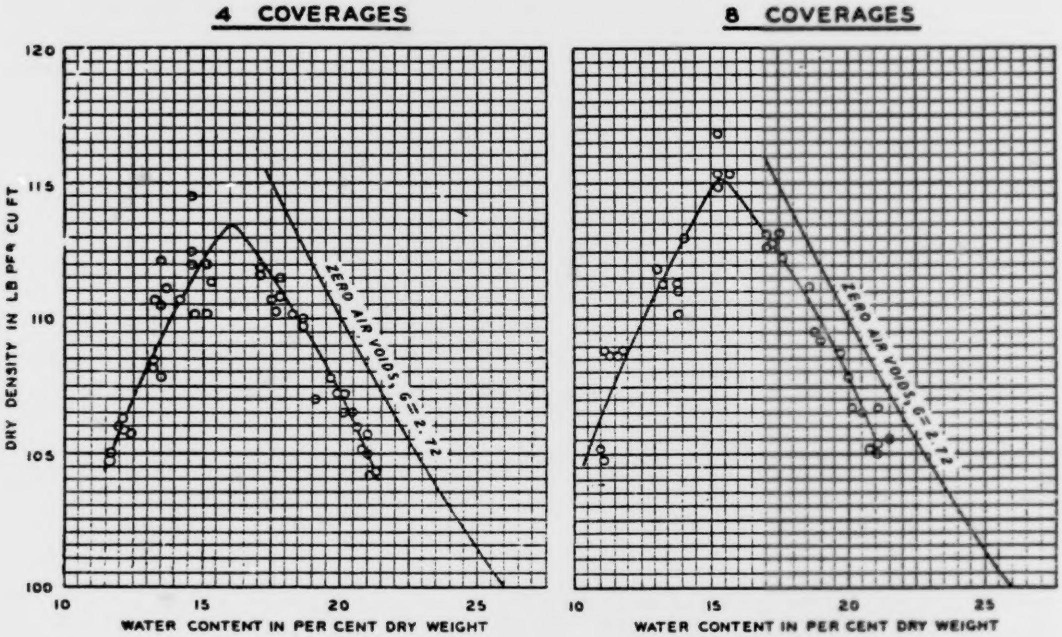
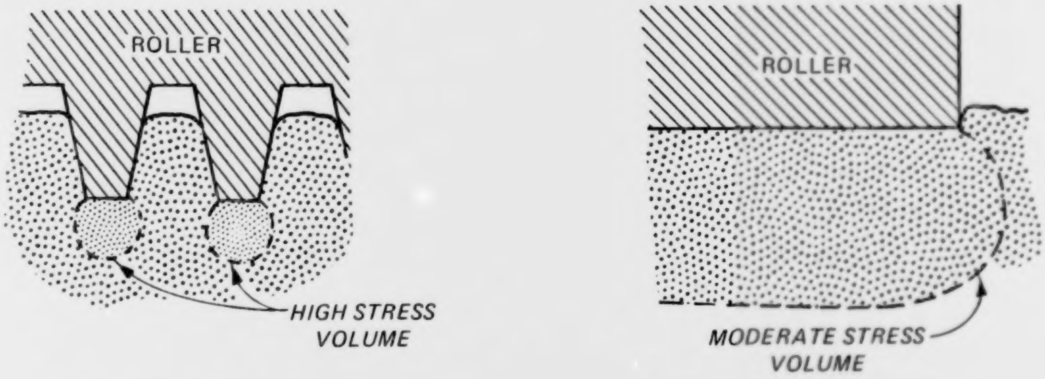


Figure 44. Effects of number of passes by sheepsfoot roller.



150-PSI TIRE PRESSURE

Figure 45. Effects of number of coverages by tire roller.


ROLLER
HIGH STRESS VOLUME
ROLLER
MODERATE STRESS VOLUME

SHEEPSFOOT ROLLER

SMOOTH ROLLER

Figure 46. Stress concentration in compaction.

even be added to specifications otherwise emphasizing performance. In considering the guidance in Table 18, the designer may want to make adjustments for differences in soil type. More passes may be necessary in poorly graded soils in comparison to well-graded soils. However, it has been observed that sand sometimes responds adversely to increased compaction by becoming less dense beyond a certain point. Vibratory compactors overcome this problem, but their suitability for solid waste management is not generally established.

Lift Thickness

Cover layers or courses exceeding about 6 inches thick should be constructed in lifts or increments to achieve the intended design. Certain simple guidance based on experience can be used in regard to appropriate lift thickness. It has been found that loose lift thickness should not exceed the length of the feet when compacting with a sheepsfoot roller. Otherwise, there is the likelihood that the feet will fail to reach the lower portion of the lift, and low densities will remain there. In marginally thick lifts there may be a tendency for local bridging to take place leaving small pockets of low density at the base. In a highly simplified explanation, not universally accepted, a sheepsfoot roller compacts from the bottom up so that eventually the entire thickness reaches a high density. The roller tends to "walk out" as the compaction zone moves upward in the lift, and ultimately, only a thin surface layer remains uncompacted.

A major disadvantage of a sheepsfoot roller in cover construction comes in its potential for damaging the layer being compacted or even affecting the layer below. If the underlying layer is a relatively thin hydraulic barrier, serious damage may result from the punching action of the feet. As long as this threat is not overlooked but instead is carefully addressed, no problems are anticipated. Of course, careful consideration may lead to the choice of another type of roller.

The effect of lift thickness in compaction with a tire roller is substantially different in that the densification is concentrated at the ground surface. This effect is illustrated in Figure 47 based upon tests specifically to clarify this phenomenon. The curves represent conditions at four depth intervals in 24-inch lifts. The top curve is for densities developed in the top 6 inches. The high density at the surface results from the concentration of stress there as is the case for any surface loading. In contrast, the sheepsfoot roller punches to depth and achieves a stress concentration there and for a given stress on the ground surface and other factors constant the same density results regardless of lift thickness. Lift thicknesses of 6, 12, and 24 inches have been studied. The decrease in density with depth in the thick lift shows clearly that individual lifts must be fairly thin in order to approach high density throughout a cover layer.

Special Methods

Slope compaction--

Compaction on a slope constitutes a special procedure that deserves special attention. Such compaction is routinely done, e.g. in constructing clay

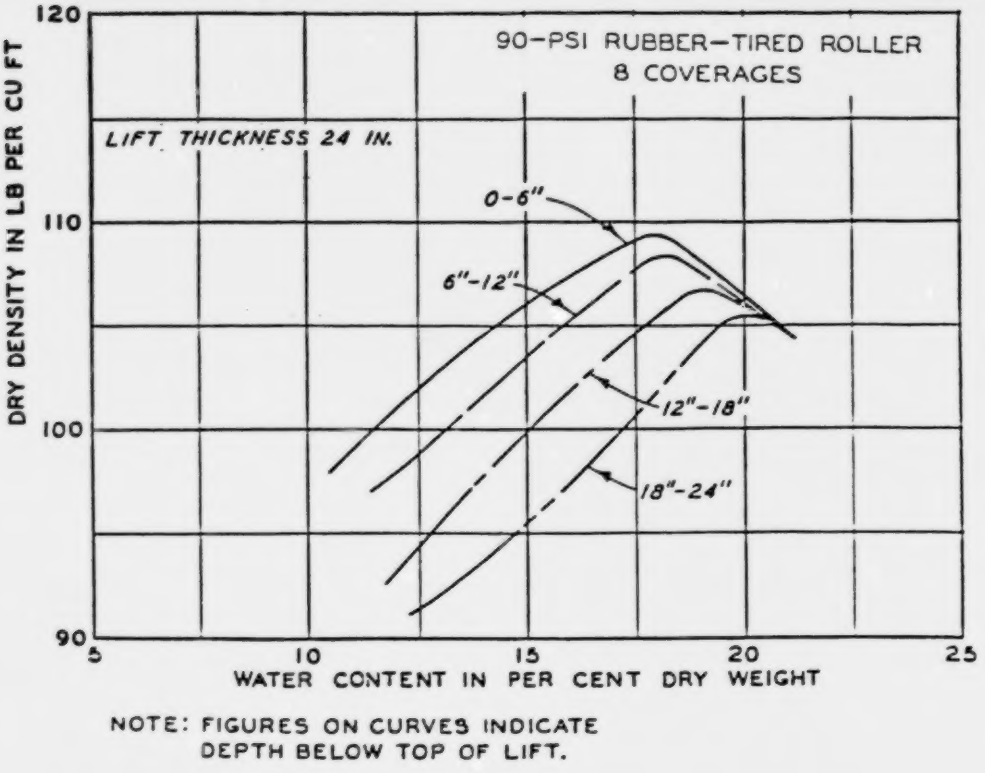


Figure 47. Density variation under surface loads such as tire rollers.

liners for irrigation canals, but certain problems may arise when the contractor is inexperienced. Compaction can be accomplished by rolling either parallel or perpendicular to contours. Figure 48 illustrates how a relatively wide compactor can be used by inclining the lifts obliquely across the layer. Alternatively the lifts may be kept horizontal and the layer overconstructed to be trimmed back at a later time. Elsewhere, slopes are rolled up and down the incline. On steep slopes a supplemental power source may be effective, such as a winch and cable (5), and may even be necessary to avoid damage where traction is difficult.

Proof rolling--

Proof rolling is sometimes used to test a road subgrade and accordingly, might be considered also for checking the adequacy of the foundation below a cover system (BUFFER LAYER OR FOUNDATION, SECTION 4). As applied in highway and airfield runway construction, a roller traverses back and forth over the

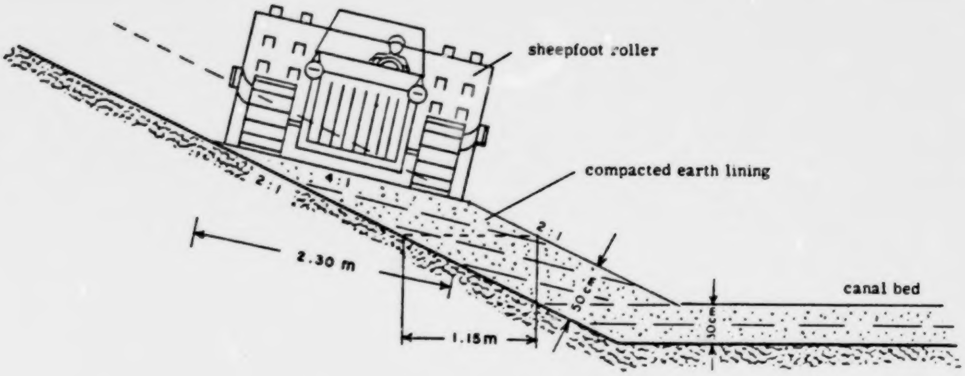


Figure 48. Compacting constraints on sloping layer from experience in canal construction.

compacted soil, and an inspector follows closely to watch for soft spots. With packaged waste and other irregularities lying at shallow depth below a waste cover system, proof rolling would help in giving much-needed assurance that the foundation is reasonably sound. Weaknesses appear in the form of concentrated rutting or evidence of wet spots or weaving plastic soils. The presence of differentially settled areas or patches of wet or plastic soils will necessitate careful consideration of the need for replacement or for addition of a buffer of select soil.

Example specifications for proof rolling highway subgrades are shown in Appendix B. Of course, proof rolling procedures for highway construction are not fully applicable to construction of cover systems. Some simplification will probably be warranted, especially in choice and use of the roller unit.

Soil-cement compaction--

Compaction of soil-cement is usually required to be completed within 60 minutes after spreading and no more than 30 minutes between operations. Compaction for embankments with 6-inch compacted lifts is accomplished in at least six passes of a sheepsfoot roller followed by at least four of a tire roller. A separate procedure would be needed in the construction appropriate for cover systems. The roller should have provision for ballast loading so that the weights can be adjusted to provide the best compaction. After compaction, the compacted layer or lift is cured by keeping the exposed surfaces continually moist using a fog spray until the overlying or adjacent layer is placed or for a minimum of 7 days. A blanket of moist soil may be used for permanently exposed surfaces. The surface of the completed layer may require brushing just before initial set and just prior to constructing an overlying layer.

Small-space compaction--

Special methods are required for compacting in small spaces where the usual compaction equipment cannot operate. When accomplished systematically, as when distinguished as a separate contract item or unit of work, small-space compaction reduces potential deficiencies in vulnerable areas -- most prominently, zones of high permeability with added susceptibility to piping and settlement. An especially vulnerable location is a narrow band above the sides and ends of trenches (Figure 49). Vibrating tampers are among effective devices used in such small spaces.

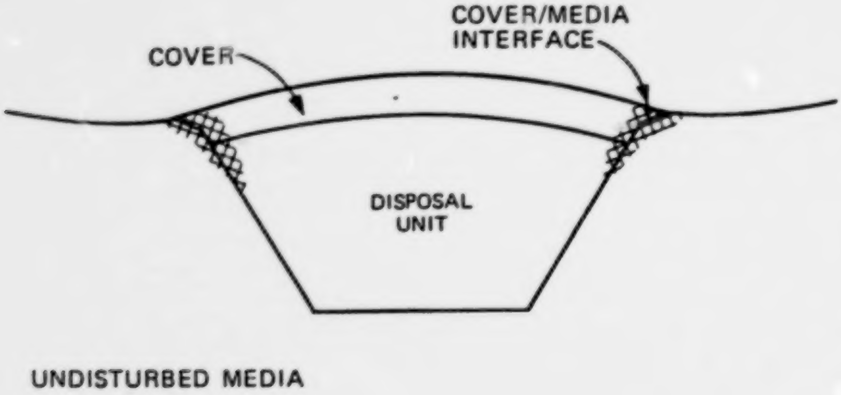


Figure 49. Boundary strip vulnerable to poor compaction.

Interface Treatment

The horizontal interface between layers or courses of the system or between lifts within each layer should be carefully reviewed for intended function and for potential problems (Figure 50). In most cases, lift interfaces are scarified or otherwise minimized to achieve a blending of the two lifts. Each layer is designed to be homogeneous and uniform, and any horizontal partings or material discontinuities between lifts within the layer simply introduce departures of uncertain significance. Interfaces between layers, on the other hand, are ordinarily to be preserved as much as possible since they separate layers having different functions. Some very specific provisions usually need to be included in specifications so that each interface is either largely removed or largely preserved. Appendix A presents some example specifications regarding scarification prior to placement of another lift.

Surcharging

The technique of surcharging can sometimes be used to circumvent the need for mechanical compaction in preparing the foundation for the cover. Surcharging is seldom feasible however on the cover itself. The procedure is to pile temporarily on the backfill, embankment, or cover foundation enough soil to accomplish a densification. As little as 5 feet of soil will have a substantial effect, and most of the effect remains after unloading. The technique is especially suited to trench disposal operations where soil removed in trenching can be placed on an adjacent filled trench. That surcharge pile is later trimmed down as the new trench requires backfilling.

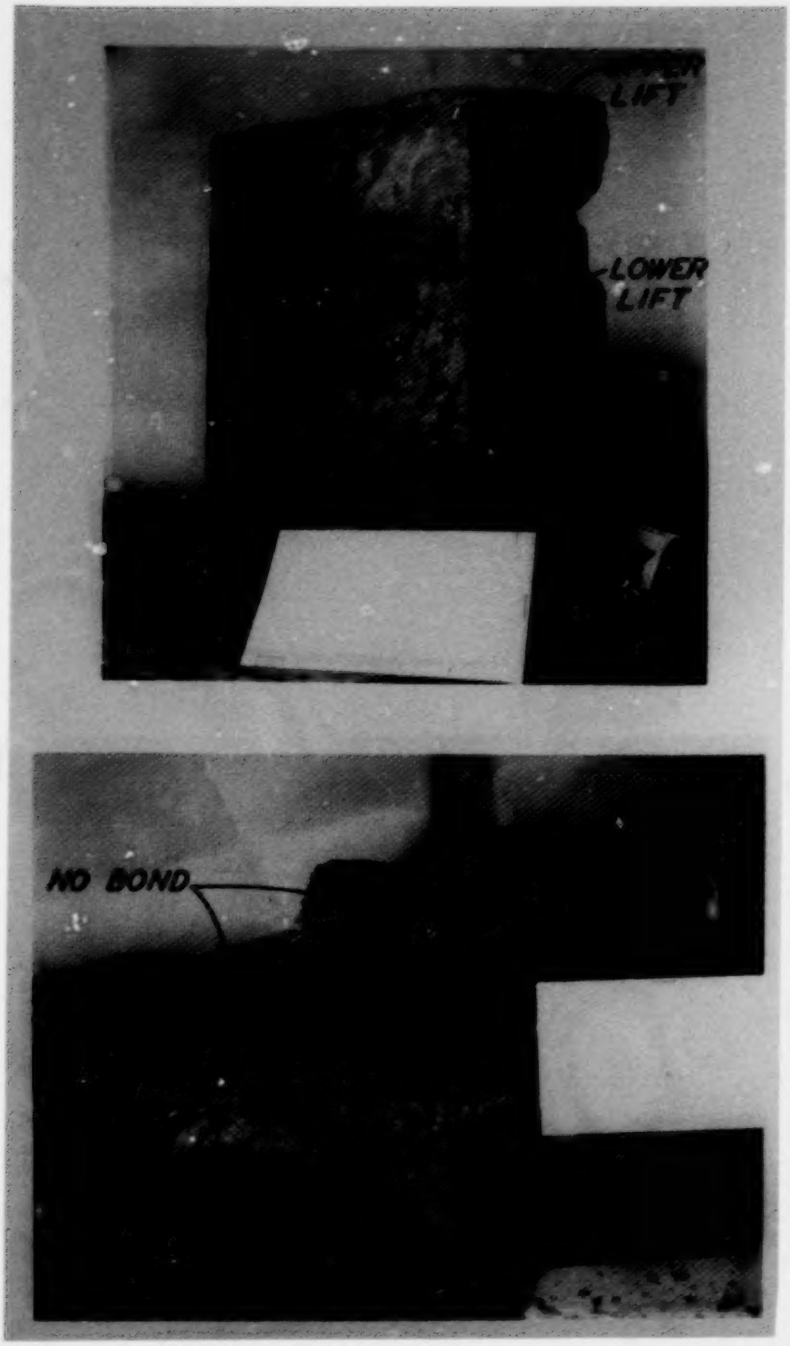

UPPER LIFT
LOWER LIFT
NO BOND

Figure 50. Poor bonding between compacted lifts.

MEMBRANE INSTALLATION

Guidance is available elsewhere (32) on design and construction of polymeric membrane liners. Most of that technical guidance is adaptable to installation of a membrane in a cover application. A unique hierarchy of steps contributes to installation of polymeric membranes: production of raw polymer components, manufacture of sheeting or roll goods, assembly of panels, and installation of the complete membrane. These four steps may even be accomplished by four separate organizations.

Production of the raw components and combination of those components with scrim and other ingredients into sheeting are carefully controlled manufacturing processes, and applicable requirements or standards can be very specifically formulated and met. Placement and seaming of sheeting after receipt from the manufacturer are not so amenable to quantification and therefore deserve extra attention in the preparation of specifications. Common problems in the past use of membranes for liners and for cover are concerned with seam failure and with puncture or abrasion during installation.

Installation of membranes proceeds in steps[1] that can be summarized as follows:

a. Choose suitable installation equipment. Emphasize obtaining units for routine and special needs. Special needs are determined by bulk form of panels (rolled or folded), membrane thickness, seaming requirements, and bedding requirements.

b. Assemble materials and equipment on site. Give special attention to minimizing deterioration of panels while handled and exposed in storage.

c. Assemble and instruct work crews. Much of the placement of the huge panels is accomplished by large coordinated crews.

d. Place the panels on smoothed soil foundation (buffer or bedding layer). Lay strip panels up and down rather than parallel to contours. Allow prescribed overlap and remove wrinkles along seam.

e. Seam with appropriate bonding or heat treatment according to recommendations of manufacturer. Keep surfaces clean and dry. Most seaming is completed by application of pressure over a firm base.

f. Follow manufacturer's instructions in sealing around penetrations such as monitoring holes, risers, and gas vents; similarly with fitted boots.

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[1] Detailed information on liners and steps in liner installation is available in technical resource document SW-870 (32).

Weather conditions affect installation through substantial effects on material and surfaces as well as effects on productivity of the crew. Warm weather is most favorable. It is generally recommended that seaming not be attempted during rainy periods. These adverse effects of harsh weather dictate that an additional step could be interposed ahead of a-f above:

> Schedule installation in the warm dry season to the extent feasible, and make provisions for minimizing disruption of schedule by unpredictable individual storms.

Since the installed membrane may experience considerable shear or tensional stress on slopes, a trench or other anchorage may be placed at the top of the slope as is done with liners. Temporary anchor points (e.g. with numerous sand bags) are usually necessary also during installation to prevent disturbance by wind gusts.

SEQUENCE

Flexibility in placing the cover construction within the sequence of operations ranges between extremes. Disposal units can be covered permanently at the earliest convenient time after filling of the disposal units. Another option is to emplace a temporary or intermediate cover and postpone the emplacement of a permanent cover system until the last disposal unit at the facility has been filled and some stabilization has occurred. A third option is to emplace the complete cover in several areal increments. In any case, the sequence of construction must follow a well-conceived plan. The consequences of leaving all or a portion of a disposal unit open to receiving water for an appreciable period must be balanced against higher cost and other consequences of covering a disposal unit in increments. Clearly, an effective system for water collection and removal is needed in either case. Sometimes the leachate collection system is used, while elsewhere sump pumps are installed in appropriate low points. Elsewhere, most runoff can be channeled away from the waste cell face (Figure 51). The interrelationship of the sequence of cover construction with other factors complicates the planning, e.g. there may be other reasons for covering disposal units quickly with intermediate cover.

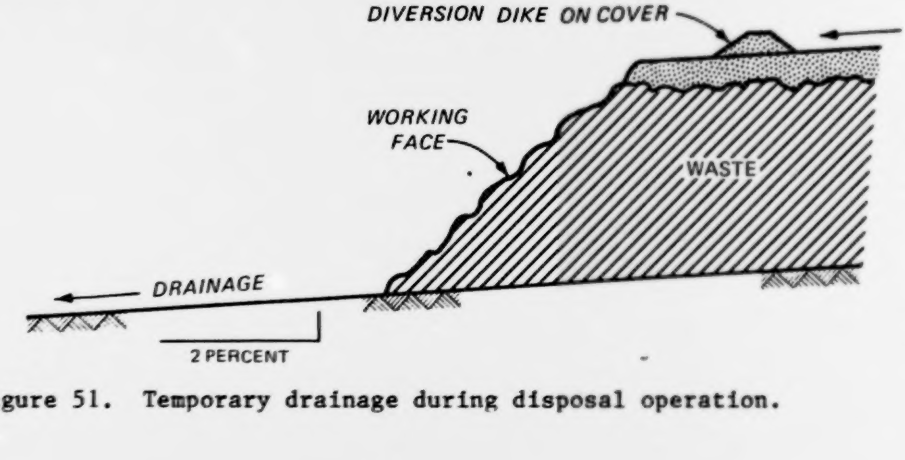


Figure 51. Temporary drainage during disposal operation.

The main possibilities for saving cost in planning the sequence are often contingent upon an early formulation in the planning process while there is still flexibility in dimensioning, positioning, and orienting the disposal units. Lesser opportunities for improvement come in lesser details and may not appear until construction is underway. Ordinarily those details of sequence formulated at a preliminary stage by a designer or reviewer conditioned to value engineering are preferred. Since a contractor building a cover system is usually motivated primarily by profit, he may prefer and choose an expedient sequence of construction, conceivably to the detriment of the cover system. Therefore, the sequence of construction should receive careful consideration by a separate reviewer such as a representative of the regulating office. Figure 41 presents a hypothetical example of effective planning in the sequence of operations on a cover completed in increments along the cell. The channels developed to divert water away from active disposal faces may be constructed as part of the permanent surface runoff system. This sequence avoids the necessity for superimposing a drainage system at a later time by making use of operational diversion ditches.

Sequencing must also be planned in regard to day-to-day construction, e.g., layer by layer over a unit area. Possible procedures are presented in Figure 52. The usual method is to construct each layer of the cover over the entire unit area. This method is optimal for layer continuity, but its large exposed surface may be vulnerable to deterioration by water evaporation on the one hand, or soaking by storm events on the other. The activity of construction equipment may also adversely affect the layer condition. Careful timing should alleviate some of these problems. It may be possible to place the upper lift of one layer and the lower lift of the next layer above in one day and thereby minimize deterioration along a critical interface (Also see INTERRUPTIONS). The size of the unit of cover under construction also can be manipulated to minimize interference. Figure 53 shows how the area undergoing compaction can sometimes be kept to a minimum in cold regions (34), in this case to guard against damaging freezes.

TEST SECTION

Field-scale testing has proven to be among the most valuable aids to earthwork construction and can be applied as well to cover construction. The achievement of desired construction results is demonstrated using the material, equipment, and procedures previously proposed as appropriate. The factors that may be explored include the following:

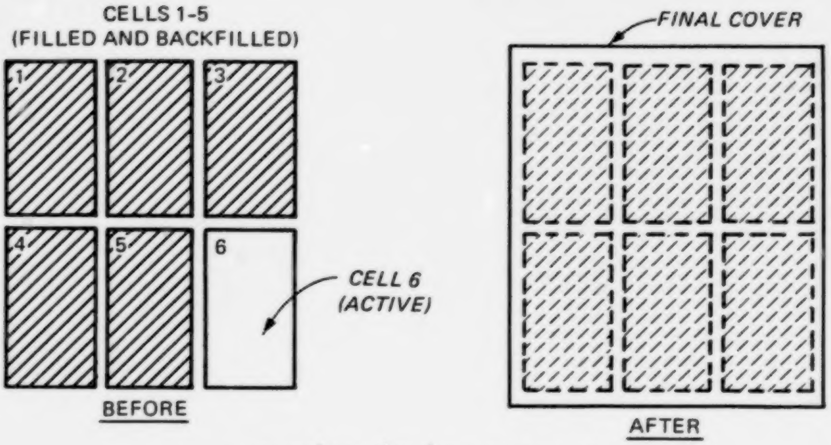
a. Selection of soils in the borrow area.

b. Distribution of soils on the cover to obtain uniformity.

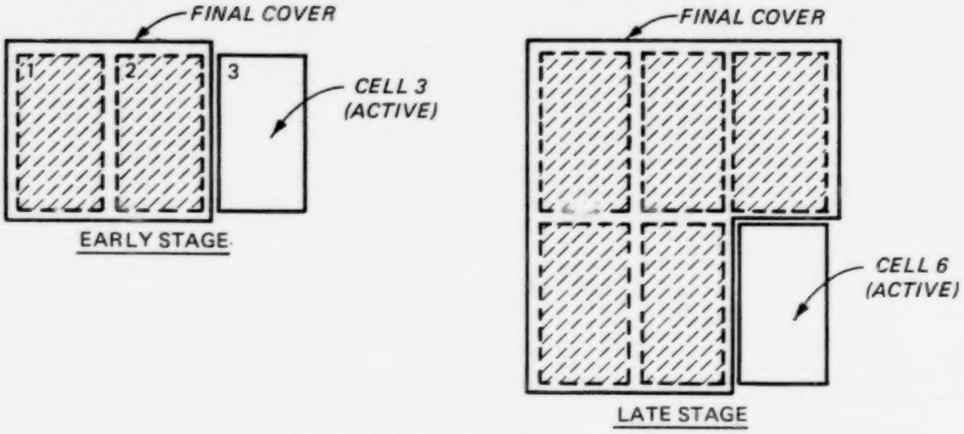
c. Water content at placement, and its uniformity throughout the soil.

d. Water content of borrow soil.

e. Methods for correcting borrow soil water content if too wet or too dry.


CELLS 1-5
(FILLED AND BACKFILLED)
1
2
3
4
5
6
CELL 6
(ACTIVE)
BEFORE
FINAL COVER
AFTER

a. ONETIME COVER CONTRACT


FINAL COVER
1
2
3
CELL 3
(ACTIVE)
EARLY STAGE
FINAL COVER
CELL 6
(ACTIVE)
LATE STAGE

b. INCREMENTAL COVERING

Figure 52. Possible procedures for areal construction.

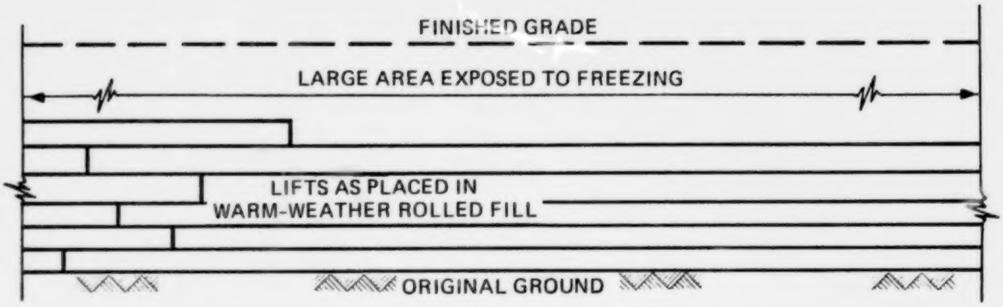
f. Compactor characteristics.

g. Number of compactor passes.

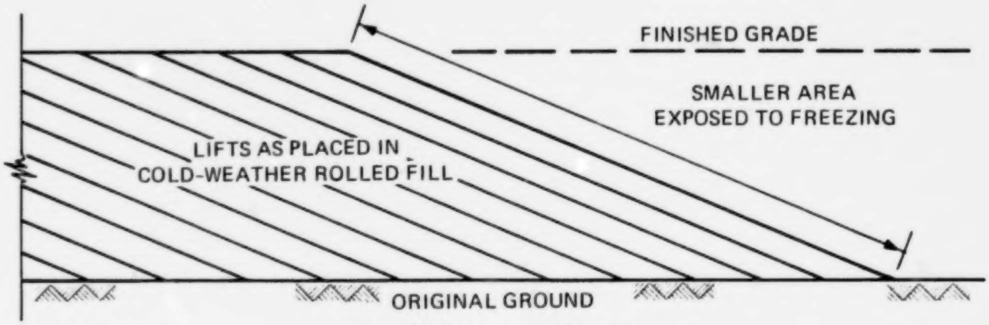
h. Thickness of lift either loose or compacted.

i. Maximum size and quantity of rock or pebbles in the material.

j. Condition of the surface after compacting.


FINISHED GRADE
LARGE AREA EXPOSED TO FREEZING
LIFTS AS PLACED IN
WARM-WEATHER ROLLED FILL
ORIGINAL GROUND

a. IN NORMAL WEATHER


FINISHED GRADE
SMALLER AREA
EXPOSED TO FREEZING
LIFTS AS PLACED IN
COLD-WEATHER ROLLED FILL
ORIGINAL GROUND

b. IN COLD WEATHER

Figure 53. Possible variation in embankment placement in warm versus cold weather.

k. Effectiveness of tamping in small places inaccessible or undesirable for roller operation.

l. Vulnerability of system, e.g. to vehicle traffic.

Though initially costly, the full-scale field demonstration is generally considered to be highly cost-effective in the long run. The sample of the cover system constructed in this manner can be examined and sampled and then tested in detail. Observations made in test pits within the test fill are the only advanced information available about complex interactions between the relatively thin layers of the cover system during loading by construction equipment. In situ tests of permeability can be made here as nowhere else to evaluate preliminarily the hydraulic characteristics of the system. The test section also provides the engineer a chance to verify the general plan and timing of operations. A need for subtle changes in sequence or timing may become evident. Finally, the results of field density tests made on the test section will provide the necessary information for establishing construction control procedures consistent with design requirements.

A test section (Figure 54) may be broadened from the objective of demonstrating suitability of chosen plans to a comparison of more than one option. In this case, the test section includes several panels where one or a few

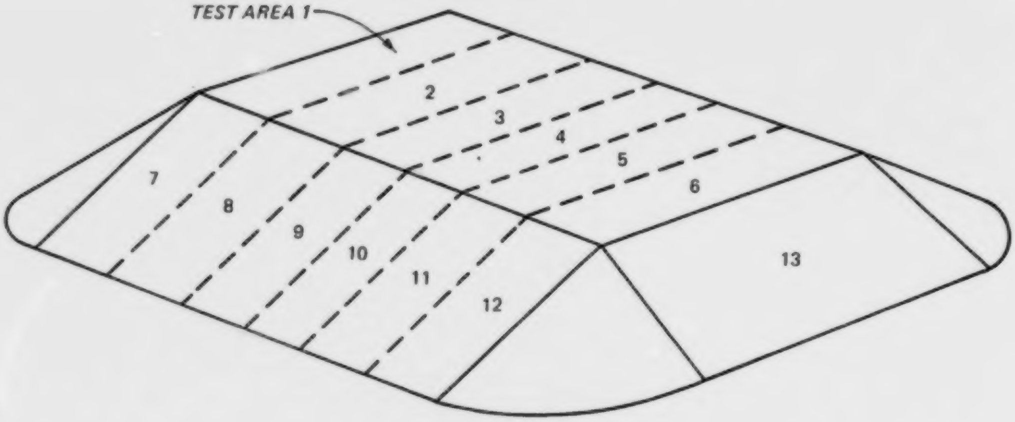


Figure 54. Plan for test section to explore parameters of design.

parameters are considered. For example, the effect of thickness may be explored in panels among which the thickness is varied but other factors are kept constant. After construction and after careful dissection, observation, or sampling and testing, a decision can be made on the best thickness for the cover layer. For example, it may then be evident that layers less than a certain thickness experience disruption by the compacting equipment chosen for use. Such a finding might necessitate a modification of what had been the tentative design in regard to thickness or equipment constraints.

INTERRUPTIONS

Construction progress can be delayed by interruptions for weather and for labor, logistical, and administrative reasons. Anticipating the importance of favorable weather, the contractor should organize the job to coincide with the construction season and make special efforts and plans to avoid extensions of work into unfavorable seasons. Workable contingency plans must also be in place to minimize unexpected delays and their effects from other causes as well as weather.

Among possible interruptions are labor strikes on site or within ancillary industry; e.g. strikes by truckers can conceivably affect the delivery of necessary materials. Administrative interruptions might develop from unexpected difficulty in attaining the required standards of construction, e.g. the specified degree of compaction of soil. Delays might also come from an office acting in a regulatory capacity.

Rain presents problems in working with clay and silt, and the preferred construction season may be limited to a few months. Cover can be constructed beyond the summer time window, but the prudent planner or contractor carefully addresses possible consequences. The following contingency measures may partly alleviate problems from rain during placement and compaction (5):

a. Blade and smooth-roll the unfinished surface to facilitate runoff.

b. Provide operational drainage to facilitate runoff.

c. Cover the system with temporary polyvinyl chloride sheeting anchored with sandbags.

d. Add lime and scarify to absorb moisture and restore workability.

e. Switch borrow area or stockpile to avoid excessive watering of soil material.

Incorporation of frozen soil into compacted layers is generally considered to be unsatisfactory practice and should not be allowed. Cold weather can also stiffen membranes and fabrics and interfere with proper placement. Construction should be scheduled to avoid cold conditions and in extreme conditions interrupted temporarily or terminated for the season.

When unseasonal cold snaps occur, certain steps may help in getting through short interruptions. A blanket of straw or soil may temporarily protect those layers of the system already in place. Otherwise the near-surface portions eventually may have to be bladed down to unaffected soil with attendant risk of damage. Possible techniques worth considering to minimize interruptions for unexpected rain or freezing in cold regions are illustrated in Figures 53 and 55.

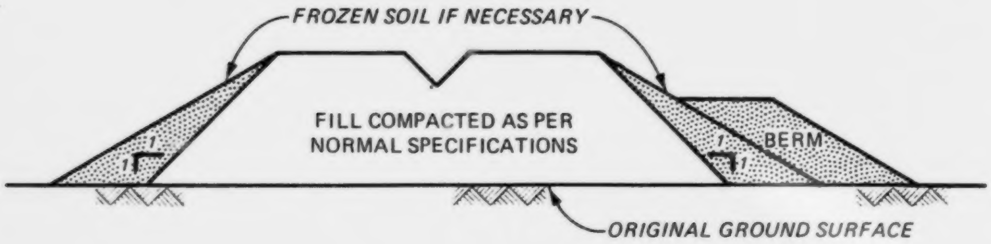


Figure 55. Contingency placement of frozen soil in noncritical areas in highway construction.

SECTION 7

CONSTRUCTION QUALITY MANAGEMENT

Basic objectives of quality management are the minimization of and compensation for unacceptable construction and materials. Necessary actions are often difficult, unpleasant, and costly. By prescribing unambiguously the general duties and perspectives of inspectors and others participating in quality management, such undesirable circumstances are also minimized. One may distinguish three similar and closely related engineering control tasks undertaken during cover system construction. The tasks of quality control, quality assurance, and acceptance inspection or testing can have important separate roles in the construction effort, or they can be combined.[1]

Where RCRA requirements are to be satisfied, the planning and implementation of construction quality management should be in agreement with guidance issued in 1986 by Office of Solid Waste and Emergency Response (46).

QUALITY CONTROL

Quality control (QC) is the contractor's way of observing, measuring, sampling, and testing for the purpose of establishing conformance or nonconformance to the plans and specifications in his daily operations. QC in earthwork contends with the complexity and variability of the soil materials and site conditions, and therefore is dissimilar from QC on a product assembly line. QC is commonly accomplished by an independent element within the contractor's organization, i.e., the contractor monitors the quality of his own work through his QC program and can adjust quickly for necessary improvements. Thorough documentation including test results is necessary to provide the findings of the program to other interested parties.

Table 20 lists important efforts in a QC program for cover construction. The QC program is built around a selection from this list. As one important example one should consider the control of soil compaction.

The contractor is usually responsible for taking or arranging for the taking of sufficient tests to ensure the adequacy of compaction. At the start of compaction many tests are required to ensure that the construction operations are producing the required results. After satisfaction has been

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[1] The distinctions made in this section reflect long-standing construction practice in the Corps of Engineers but are not universally established. Therefore, each application should be carefully defined.

TABLE 20. IMPORTANT ASPECTS OF QC PROGRAMS

Assessment of foundation for supporting the cover system

Confirmation of soil composition, especially particle-size distribution, including any blending

Assessment of soil placement, including equipment operation

Assessment of buffer or other layers immediately below and above a barrier layer, for smoothness and fineness

Assessment of compaction equipment and procedure for compatibility with material and design

Confirmation of moisture control

Assessment of compaction results largely as manifested in unit weight

Assessment of synthetics placement with emphasis on defects, damage, and overlaps

Confirmation of synthetics seaming

Tracking of retrofitting work for drainage control and other special features

Confirmation of seams, boots, and other seals around vents and access holes penetrating the cover system

Assessment of vegetation plan and schedule

established, the number of tests required are only those necessary to ensure that specifications requirements continue to be met. The number of field density tests required for adequate control cannot be stated generally. Testing requirements should be based on area as well as on volume and should be developed site-specifically. Some guidance can be found below with test requirements for more general construction of the Bureau of Reclamation.

a. For all types of earthwork, one test for each shift.

b. For canal embankments, one test for each 2,000 cubic yards.

c. For compacted canal linings, one test for each 1,000 cubic yards.

d. For compacted backfill or for refill beneath structures: hand tamped (mechanical tamping), one test for each 200 cubic yards; roller or tractor tamped, one test for each 1,000 cubic yards.

e. For soil-cement earthwork, one test per 500 cubic yards or at least two tests for each shift.

When field density tests are taken in relatively narrow areas where equipment travel is essentially along one route, care should be taken to avoid sampling these paths. The density may be anomalously high there.

Horizontal and vertical survey control must be available so that the inspector can adequately locate each field density test. Locations are usually defined in terms of station, offset from centerline, and elevation above bottom grade. The inspector is responsible for locating these tests so that a complete representative record of the finished work is available.

Compaction tests for clayey and silty soils and relative density tests for free-draining sand and gravel soils should be made. These companion tests are required for each control field density test to compute the percent compaction or relative density, respectively.

QUALITY ASSURANCE

A quality assurance (QA) program obtains extra confidence for the owner or regulator in the quality of construction and conformance to plans and specifications through documentation similar to QC. Such programs play a key part in the extensive earthwork construction of the Corps of Engineers. The QA is conducted by or for the engineer[1] (in government parlance the contracting officer) and amounts to inspection and testing to confirm the adequacy and results of the contractor's QC program.

QA has previously been assigned widely divergent importances in solid waste disposal. Occasionally, a QA program was established but more commonly there was none. Elsewhere, there has been a loose combination of QA with QC, e.g. in disposal of low-level radioactive waste (47). A QA program is now required for new RCRA facilities.

In a preliminary stage, the QA personnel must have a clear understanding of construction QC requirements before their first examination of the contractor's QC or discussions with the contractor. The personnel should study all contract QC provisions that establish the contractor's requirements as well as the parameters for QA personnel participation. The QC plan and its relation to QA and QA personnel should be reviewed next.

Specifically, the engineer should:[2]

a. Assign QA responsibilities to his staff and assure that their duties and authority to act are clearly understood. Assign one individual as the coordinator for QC.

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[1] As envisioned by EPA in the pertinent RCRA guidance document (46), QA is responsible to but functions apart from the facility owner/operator.

[2] The distinctions made in this section reflect long-standing construction practice in the Corps of Engineers but are not universally established. Therefore, each application should be carefully defined.

b. Ascertain that his staff understands the contract requirements, knows the inspection and test techniques to be used, and realizes the need for timely inspections and tests.

c. Establish standards for daily QA reports and ascertain that the reports are pertinent, factual, and complete.

d. Establish with QA personnel and laboratory personnel a clear understanding of the actions to be taken in the handling and correction of deficiencies observed.

During construction, QC and QA should interact as follows:

a. The QA and QC representatives should have jobsite discussions on the interrelationship of their activities during the preparatory phase. Discussions should emphasize controls necessary to eliminate routine construction deficiencies.

b. The QA supervisor should be knowledgeable of contract requirements for each phase of work; participate in preparatory, initial, and follow-up phases; make joint inspections with QC personnel to evaluate their effectiveness; review QC reports for completeness and accuracy; note and report deficiencies and direct contract compliance; and check to see that QC is producing prompt corrections of deficiencies and control problems.

c. The contractor should not be permitted to build upon or conceal any feature of the work containing uncorrected defects. Payment for deficient items will be withheld until they are satisfactorily corrected or other action is taken according to any general provision clause concerning inspection and acceptance.

d. The engineer should test to assure acceptability of the completed work and to verify QC test procedures and results. QA testing should be concentrated on completed work at unannounced intervals. The engineer should verify the accuracy and calibration of equipment, assure correct application of specified test standards, and verify the coverage and accuracy of required QC tests. Test reports, which should be submitted as attachments to the contractor's control reports, should be reviewed by the engineer, engineering or laboratory personnel, and/or the QA personnel assigned to the work, depending upon the type of test.

e. The plan of contractor submittals should be carefully checked to assure that all items of material and equipment needing documentation are included. The reasonableness of the schedule dates should be examined and the contractor informed of any found to be unrealistic. The contractor's certified submittals should be checked in a timely manner to ensure that installation details, materials, and equipment comply with contract requirements. The contractor should be notified of any deficiencies.

f. Some QA testing in the case of critical earthwork must be conducted continuously. During the stages of material processing, placement, and compaction a comprehensive control and assurance testing program is necessary.

ACCEPTANCE CONTROL

Acceptance testing and reports are sometimes considered a part of quality assurance programs but elsewhere are a separate type of quality management. Confirmation of the quality of incoming materials is one aspect detailed in Appendix B through the example of bituminous concrete. Another viewpoint in construction of hazardous waste facilities comes through a potential need for quality management at a high level, e.g., a state or federal regulatory agency. Clearly, the term acceptance implies the adequacy of a portion of the constructed system. Accordingly, the term probably should never be used in another, less definite context. Under the circumstances where the owner or a regulatory office conducts or contracts for acceptance tests, it would be expected that the parameter being tested would be a fundamental and significant one rather than an index property of only secondary importance or indefinite significance. Accordingly, the coefficient of permeability is potentially an important acceptance test parameter, whereas compacted earth density is usually not.

The specifications for bituminous concrete in Appendix B illustrate acceptance testing and methods in construction by example from highway pavement construction. The example of bituminous concrete material is not directly applicable to typical cover construction but is intended to be useful to experienced engineers by indicating generally the sophistication that has been incorporated into similar construction.

Table 19 presents several construction tests and inspection procedures also useful in determining the acceptability of portions of a cover system. Also see Table 11. Of course, some criterion, standard, or cutoff value usually must accompany such procedures to develop their full value. Setting such limits is no small task, but a first cut can be accomplished by an experienced engineer adapting guidance in this document to the specifics of the project.

SECTION 8

VEGETATION ESTABLISHMENT[1]

The role of vegetation in the cover system is to protect surficial soil against erosion and disruption. Although there is an urgency in establishing protection over the vulnerable, newly constructed cover system, the long-term health of vegetation is of even greater importance. Accordingly, the guidance in this Section should be intermeshed with recommendation in Section 10 on maintaining an effective condition into the long term.

SPECIAL CONSIDERATIONS

Sound, vigorous vegetation on the cover system is highly cost-effective. Primary benefits are often identified as decreases in erosion by wind and water. Vegetation reduces raindrop impact and runoff velocity and strengthens the soil mass with root and leaf fibers. At the same time, however, the soil's infiltration capacity is detrimentally increased so that considerable water enters. The increased infiltration is offset at least partly by transpiration from vegetation, but the relative importance of these offsetting processes is a complicated question approachable only on a site-specific basis.

Rapid establishment and maintenance of perennial vegetation or self-reseeding annual vegetation can be accomplished on a cover system only by carefully addressing soil type, nutrient and pH levels, climate, species selection, mulching, and seeding time. Fertile soils, if available at all, are sometimes cost-prohibitive so that soils or subsoils that are nonproductive alone often have to be used. The vegetative layer of a cover system tends to be relatively shallow.

These shortcomings of the vegetative soil layer are compounded where the cover system has been designed to impede percolation. A clay or membrane barrier layer makes the plant-root zone above it susceptible to swamping after rains since vertical drainage is impeded or blocked. Upon saturation, the soil becomes anaerobic, a condition which, depending upon the duration, may kill progressively larger roots. Short periods of swamping weaken the vegetation; longer periods may cause a complete loss.

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[1] This section is a modification of the corresponding sections in the previous reports (2,3).

At the other extreme, a thin vegetative layer dries excessively during dry periods. No deep-soil moisture is available to tide the plants over even moderate droughts. Plants that have been weakened by prior waterlogging or that are not drought-tolerant are especially vulnerable. Irrigation will help during prolonged dry spells to prevent deterioration of plant cover, but one prefers to avoid costly maintenance, even on an irregular basis.

Some disposal units have the potential to produce gases and soluble organic decomposition products years after closure, and vegetation can be damaged. Fine-grained soil layers help shield shallow plant roots from gases and leachate. On the other hand, shrubs and trees may penetrate the cover with long roots and cause leaks of water into and gases from the disposal unit. Inspection of damaged vegetation on regional landfills and disturbed lands can help identify vulnerabilities and disadvantages of plant species.

MANIPULATING SOIL FACTORS

Major factors determining effectiveness of the soil for supporting vegetation are grain size, pH level, and nutrient content. Laboratories capable of evaluating soil for these factors are located throughout the United States, and most county agents can provide guidance. Sampling should be representative of all soils to be used (depths and areas) since the cover will usually consist of a mixture. Table 21 indicates typical ranges of organic matter and nutrients in soils for various levels of plant vitality.

TABLE 21. PLANT VITALITY LEVELS IN TERMS OF ORGANIC MATTER AND MAJOR NUTRIENTS IN SOILS (48)

	Organic Matter, percent					
Relative Level*	Sand, Loamy Sand	Sandy Loam, Loam, Silt Loam	Clay Loam, Sandy Clay, Clay	Nitrogen lb/acre	Phosphorus lb/acre	Potassium lb/acre
Very low	<0.6	<1.6	<2.6	<20	<6	<60
Low	0.6-1.5	1.6-3.0	2.6-4.5	20-50	6-10	60-90
Medium	1.6-2.5	3.1-4.5	4.6-6.5	50-85	11-20	91-220
High	2.6-3.5	4.6-5.5	6.6-7.5	85-125	21-30	221-260
Very high	>3.5	>5.5	>7.5	>125	>30	>260

*Medium level is typical of agricultural loam soil. Low levels need supplemental fertilization; high levels need no fertilization under normal circumstances.

Grain Size

A rating of USCS soil types for the support of vegetation is given in Table 9. A loam is generally overall best soil type as it is easily kept in good physical condition and is conducive to good seed germination and easy penetration by roots. Clay-rich soils may be productive when in good physical condition, but they require special management methods to prevent puddling or breaking down of the clay granules. Silt-rich soils lack the cohesive properties of clay and the grittiness of sand, are water retentive, and usually are easily kept in good condition. Soils made up largely of sand can be productive if sufficient organic matter is present internally or as a surface mulch to hold nutrients and moisture; sandy soils tend to dry out very rapidly and lose nutrients by leaching. Although classification can be estimated by visual inspection, soil typing by an appropriate soil testing laboratory is preferred. Rather minor differences in soil type can influence selections of vegetation and mulch.

Flexibility for improving the chosen cover soil may be found in carefully considering some inert wastes as additives. Fly ash has locally been mixed with cover soil to provide good soil texture with enhanced water retention capacity. The alkalinity of fly ash may also provide an advantageous complement to acidic soils.

pH Level

The pH of the soil is an important factor to be considered. If the pH is greater than about 8, the solubilities of phosphorus, iron, zinc, and manganese are so low that the plant cannot take up these nutrients even though they are present in sufficient quantities. If the soil pH is below 5, the concentrations of soluble manganese and aluminum often are high enough to be toxic and the availability of molybdenum and phosphorus is limiting.

The amount of lime necessary to neutralize a given soil depends upon soil pore water pH and reserve acidity. The reserve acidity, or buffering capacity, is a single factor that incorporates several variables; soils with high levels of organic matter and/or clay require higher amounts of lime for pH adjustment. The usual way of characterizing the buffering capacity is as tons per acre of lime necessary to adjust the soil pH to about 6.5.

The pH of borrowed subsoil may be particularly critical to lime requirements. Some vegetative layers on cover systems are mixtures of soil and subsoil, in some cases from more than one locality. Subsoil is used in abundance for barrier layer and other components below the topsoil, and these layers may ultimately interact with the topsoil and vegetation. Acidic subsoils need larger amounts and repetitive applications of lime. Buried wastes may act much like acidic subsoils, so that lime applications may be beneficial in the backfill and intermediate cover where they merge as foundation immediately below the cover system. However, lime can alter properties of clayey soil (2), so the agronomical benefits may possibly be at the expense of desired physical properties.

Nitrogen and Organic Matter

Nitrogen is of special importance in establishing vegetation because it is needed in relatively large amounts (Table 21) during vigorous growth, is easily lost from the soil, and is the most expensive nutrient to supply. All but a small part of soil nitrogen exists in organic forms, both in decaying plant material and in the microorganisms decomposing the organic matter. Measurements of the nitrogen content of soil and its organic content are intimately related. Nitrogen accumulates in soil microorganisms where it is used over and over again as old cells die and new ones are formed. The nitrogen contained in the microbial cells is unavailable for use of plants growing on the soil until the organisms die. The rate at which nitrogen is released by breakdown of organic matter depends upon the moisture and temperature conditions in the soil. High or low moisture retards release; high temperature and moderate moisture levels produce maximum release rates.

Since many cover soils consist largely of subsoils or mixtures of subsoil and topsoil, they can be assumed to be low in organic matter content. The most cost-effective method of adding organic matter is by mulching with straw, cellulose, etc. Once vegetation becomes established, the plants themselves will add organic matter.

The amount of nitrogen fertilizer required by a given soil depends upon the amount of organic matter present (Table 21), the soil texture (more is required on sandy soils)[1], the seed mixture chosen (more is required for grasses than legumes), the criticalness of the area (potential for erosion damage), and economic factors (nitrogen fertilizer is the most expensive). Generally 50 to 85 pounds/acre of nitrogen are recommended (Table 21) for cover seeded with grass. Prior to the second growing season may be a particularly effective time for nitrogen additions in grass. It is usually most effective, however, to include nitrogen-fixing species as major components of the vegetation community.

Phosphorus

Much less phosphorus than nitrogen is held in the organic portion of the soil, and subsoils are conspicuously deficient. Accordingly, phosphorus is sometimes the key to vegetating subsoils (49). Results of phosphorus tests are commonly expressed as pounds of readily extracted phosphorus per acre-furrow slice (6-inch depth). Representative levels are shown in Table 21. Unlike nitrogen, phosphorus is not mobile in the soil and thus is lost very slowly to leaching. One application of phosphorus usually will last several growing seasons, but elsewhere legumes have benefited especially from additions before the second growing season.

Generally, at least 15 pounds/acre of phosphorus (35 pounds/acre P_2O_5) is recommended as a starter. The availability of phosphorus to the plant is quite dependent on pH. At optimum pH values (6.2-6.8), amounts of 50 pounds/acre (115 pounds/acre P_2O_5) are usually adequate; at pH values below 6.2 or between 6.9 and 7.5, about 80 pounds/acre (184 pounds/acre P_2O_5) are needed for optimum growth. Under very alkaline conditions (pH greater than 7.5), phosphorus levels of 110 pounds/acre (253 pounds/acre P_2O_5) are required.

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[1] Note, however, in Table 21 that texture and organic content tend to be interrelated also.

These recommendations are for raw subsoils or for sandy or high clay soils of low organic material content.

Potassium

Potassium is much less important in grass establishment than in legume establishment and maintenance; thus, the rate of application depends upon both test results and species to be seeded. A minimum application of 26 pounds/acre of potassium (32 pounds/acre K_2O) as a starter is recommended under any circumstances. Applications can run as high as 230 pounds/acre of potassium (277 pounds/acre K_2O) on impoverished soils where legumes are to be seeded. Potassium is moderately mobile in the soil and is slowly leached out, but one heavy application should be adequate for several growing seasons.

Other Nutrients and Toxic Materials

Other mineral nutrients needed in small amounts by all plants for adequate growth are usually present in most soils, or as impurities in typical fertilizers, and thus are not determined in typical soil tests. Deficiencies rarely limit plant growth and should be suspected only under unusual circumstances.

Soils with toxic levels of heavy metals or with high levels of salts present special problems, and their use as final cover material should be avoided unless no other soils are available. Toxicity may also need to be considered where waste materials such as fly ash, phosphogypsum, manure, etc. are added to the topsoil, but this is not anticipated as a major problem. If these soils must be used, selection of tolerant plant species is usually the most effective way to overcome the associated problems. In general, soils that support an adequate or reasonable level of vegetation in their native state will not present toxicity problems when used in the cover system.

CHOICE OF VEGETATION

General guidance in selection of plants and time of seeding is provided below. More specific supplemental data may be available from county agents or seed companies. State highway agencies are also very knowledgeable on the subject.

Species Selection

Each species of grass, legume, shrub, or tree has its climatic, physiographic, and biological strengths and limitations. Moisture, light, temperature, elevation, aspect, balance and level of nutrients, and competitive cohabitants are all parameters that favor or restrict plant species. The selection of the best plant species for a particular site depends upon knowledge of plants that have the desired characteristics. Table 22 gives the major parameters usually important to species selection and examples of grasses and legumes exhibiting these parameters. Particularly important characteristics are low growing and spreading from rhizomes or stolons; rapid germination and development; and resistance to fire, insects, and disease.

Plants that are poisonous or are likely to spread and become noxious should be avoided.

A very large number of species of grasses and legumes are available for reclamation use. Species that find wide and frequent application are described in Tables 23 and 24. It is usually advantageous to favor regional vegetation for its adaptability as well as for harmonious aesthetics. Consideration should also be given to future use of the site, supplemental to waste management. Where swampy or droughty conditions are anticipated because of climate, cover configuration, or soil type, special consideration should be given to swamp-tolerant or drought-resistant species.

Time of Seeding

Probably the most critical of all factors in the successful establishment of vegetative cover on poor soils is the time of seeding. The optimum time of seeding depends on the species selected and the local climate. Tables 23 and 24 recommend times for certain grasses and legumes based on local conditions.

Most perennials require a period of cool, moist weather to become established to the extent that they can withstand a cold winter freeze or hot summer drought. For most species in most localities, early fall seeding (late August in the north through early October in the south) allows enough time for the plants to develop to the stage that they can withstand a hard winter. Plants then have a good start for early spring growth and can reach full development before any hot summer drought. Early fall planting makes germination and early growth possible in warm weather, despite the weather growing cooler as the plants develop. Spring planting is usually second choice for all but a few of the more rapidly developing perennials. Germination and early development are slowed due to the cool early spring weather. Late frosts often severely damage the young plants. Late spring planting does not allow enough time for most perennials to mature before summer, and annual weeds will usually out-compete the preferred perennial species.

Annuals generally are best seeded in spring and early summer. They complete their growth quickly before the summer heat arrives and the soil moisture is depleted. Thus, in late spring and in summer the annuals easily out-compete the perennials. Annuals can, however, be planted for quick vegetative cover any time the soil is damp and warm.

SEED AND SURFACE PROTECTION

Bare soil as a seeding medium suffers from large temperature and moisture fluctuations and from rapid degeneration due to wind and water erosion.

Mulch in General

Mulches make the establishment of suitable plant cover more efficient by reducing evaporation, moderating soil temperatures, preventing crusting, increasing rain infiltration, and controlling wind and water erosion. Mulches also help to overcome deficiencies in organic matter typically found in

TABLE 22. IMPORTANT CHARACTERISTICS OF GRASSES AND LEGUMES

Characteristic	Degree *	Common Examples
Texture	Fine	Kentucky bluegrass, bentgrass, red fescue
	Coarse	Smooth bromegrass, reed canarygrass, timothy
Growth height	Short	Kentucky bluegrass, buffalograss, red fescue
	Medium	Redtop, perennial ryegrass
	Tall	Smooth bromegrass, timothy, switchgrass
Growth habit	Bunch	Timothy, big bluestem, sand dropseed, perennial ryegrass
	Sod former	Quackgrass, smooth bromegrass, Kentucky bluegrass, switch grass
Reproduction	Seed	Red and alsike clover, sand dropseed, rye, perennial ryegrass, field bromegrass
	Vegetative	Prairie cordgrass, some bentgrasses
	Seed and vegetative	White clover, crownvetch, quackgrass, Kentucky bluegrass, smooth bromegrass
Annual	Summer	Rabbit clover, oats, soybeans, corn, sorghum
	Winter	Rye, hairy vetch, field bromegrass
Perennials	Short-lived	Timothy, perennial ryegrass, red and white clover
	Long-lived	Birdsfoot trefoil, crownvetch, Kentucky bluegrass, smooth bromegrass
Maintenance	Difficult	Tall fescue, reed canarygrass, timothy, alfalfa
	Moderate	Kentucky bluegrass, smooth bromegrass
	Easy	Crownvetch, white clover, birdsfoot trefoil, big bluestem
Shallow rooted	Weak	Sand dropseed, crabgrass, foxtail, white clover
	Strong	Timothy, Kentucky bluegrass
Deep rooted	Weak	Many weeds
	Strong	Big bluestem, switchgrass, alfalfa, reed canarygrass
Moisture	Dry	Sheep fescue, sand dropseed, smooth bromegrass
	Moderate	Crested wheatgrass, red clover
	Wet	Reed canarygrass, bentgrass
Temperature	Hot	Lehman lovegrass, fourwing saltbush, ryegrass
	Moderate	Orchard grass, Kentucky bluegrass, white clover
	Cold	Alfalfa, hairy vetch, smooth bromegrass, slender wheatgrass

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*Variety, specific characteristic, subcharacteristic, or favored condition.

TABLE 23. GRASSES COMMONLY USED FOR REVEGETATION[*]

Variety	Best Seeding Time	Seed Density[†] seeds/ft^2	Important Characteristics	Areas/Conditions of Adaptation
Redtop bentgrass	Fall	14	Strong, rhizomatous roots, perennial	Wet, acid soils, warm season
Smooth bromegrass	Spring	2.9	Long-lived perennial	Damp, cool summers, drought resistant
Field bromegrass	Spring	6.4	Annual, fibrous roots, winter rapid growth	Cornbelt eastward
Kentucky bluegrass	Fall	50	Alkaline soils, rapid grower, perennial	North, humid U.S. south to Tennessee
Tall fescue	Fall	5.5	Slow to establish, long-lived perennial, good seeder	Widely adapted, damp soils
Meadow fescue	Fall	5.3	Smaller than tall, susceptible to leaf rust	Cool to warm regions, widely adapted
Orchard grass	Spring	12	More heat tolerant but less cold resistant than smooth bromegrass or Kentucky bluegrass	Temperate U.S.
Annual ryegrass	Fall	5.6	Not winter hardy, poor dry land grass	Moist southern U.S.
Timothy	Fall	30	Shallow roots, bunch grass	Northern U.S., cool, humid areas
Reed canarygrass	Late summer	13	Tall coarse, sod former, perennial, resists flooding and drought	Northern U.S., wet, cool areas

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[*] Taken from many sources, but especially References 48 and 50.

[†] Number of seeds per square foot when applied at 1 pound/acre.

landfill cover soils. Almost any material spread, formed, or simply left on the soil surface will act as a mulch. A wide variety of materials is used commonly or under special circumstances: straw and other crop residues, sawdust, wood chips, wood fiber, bark, manure, brush, jute or burlap, gravel, stones, peat, paper, leaves, plastic film, and various organic and inorganic liquids.

The effectiveness of any mulch depends upon many factors including the physical and chemical properties of the soil, the land-forming or cultural practices, species to be seeded, and the characteristics of the mulch itself such as its color, roughness, and manner of application. The effect of color and roughness are directly related to the radiation balance at the soil surface and, consequently, the heat transfer into and out of the soil. Slope, aspect, and orientation of the soil surface also influence the solar energy input. Other factors determining mulch efficacy are steepness and length of slope, soil texture and depth, rate of application of mulch, and the weather before, during, and after mulch application. Selection depends upon characteristics of the area to be stabilized and the availability, cost, and properties of the mulch material. Several of the more common and effective mulches and their applications are described below.

TABLE 24. LEGUMES COMMONLY USED FOR REVEGETATION*

Variety	Best Seeding Time	Seed Density† seeds/ft^2	Important Characteristics	Areas/Conditions of Adaptation
Alfalfa (many varieties)	Late summer	5.2	Good on alkaline loam, requires good management	Widely adapted
Birdsfoot trefoil	Spring	9.6	Good on infertile soils, tolerant to acid soils	Moist, temperate U.S.
Sweet clover	Spring	6.0	Good pioneer on non-acid soils	Widely adapted
Red clover	Early spring	6.3	Not drought resistant, tolerant to acid soils	Cool, moist areas
Alsike clover	Early spring	16	Similar to red clover	Cool, moist areas
Korean lespedeza	Early spring	5.2	Annual, widely adapted	Southern U.S.
Sericea lespedeza	Early spring	8.0	Perennial, tall erect plant, widely adapted	Southern U.S.
Hairy vetch	Fall	0.5	Winter annual, survives below 0°F, widely adapted	All of U.S.
White clover	Early fall	18	World-wide, many varieties, does well on moist, acid soils	All of U.S.
Crownvetch	Early fall	2.7	Perennial, creeping stems and rhizomes, acid tolerant	Northern U.S.

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*Taken from many sources, but mainly from References 48 and 50.

+Number of seeds per square foot when applied at 1 pound/acre.

Crop Residues

Crop residues such as straw and hay are readily available and are widely used mulches; and of these, straw is by far the most common mulch in all parts of the United States. Straw's fibrous texture is excellent for erosion control, and the low nutrient value retards rotting so that straw normally lasts a full season. Straw reflects much sunlight and thus may have the disadvantage of keeping the soil cool early in the spring or late in the fall, when warmth would facilitate germination and early growth.

Where erosion is not a problem, an application of 1.5 tons/acre is recommended. On slopes or where erosion is expected to be a problem, 2 tons/acre produces better results. Application rates over 2.5 tons/acre often result in reduced germination and emergence, and such high rates should be avoided. Beater-type spreaders work well on level areas, but blower types are better for steep slopes. Baled material tends to fall in bunches unless cut or shredded and scattered or blown. Wheat straw is generally preferred over oat straw since oat straw decays more rapidly and usually contains seeds that compete with the perennials for space and water. Hay, in comparison to straw, is difficult to spread, and it decomposes rapidly. However, hay possesses some nutritive value and reflects less solar radiation. Overall, however, the best plant-residue mulch is the one most available and nearest.

Straw should be anchored, if possible, so that it does not blow or wash, making piles and leaving bare spots. A disk harrow (with disks set straight) that is run over the mulch across the slope is effective at anchoring. Notched disks work best. Running over the mulch with a special punch roller or a cultipacker also helps to anchor it. Even running over the spread straw with a dozer is useful. Asphalt or resins can be used as a binder or to anchor, but while they greatly increase effectiveness, they also increase cost.

Crop residues produced in place can be effective in special circumstances. Rapidly growing crops are especially useful as temporary cover when placed in late spring or early summer since chances of successfully seeding perennial grass-legume then are low. Subsequently, the summer annual crop acts as a natural mulch for fall or spring seeding of the permanent seed mixture. Rapid-growing, coarse grasses, such as Sudan grass or a local equivalent, are good choices as they are widely adaptable and the tall stiff stalks are effective as a mulch. One disadvantage of the summer cover crop regime is that the crop depletes available soil moisture in dry areas, causing the seeding of perennials to fail. On the other hand, in wet areas, the soil under the cover crop dries very slowly and often remains too wet to fertilize and work into a good seed bed, even into the next spring.

Wood Residues and Paper

Wood residues such as sawdust, wood chips, bark, and shavings are used extensively in many areas. Wood residues are a concentrated source of organic matter, and supplementary nitrogen should be applied with the mulch. Advantages of wood residues are that they are easy to apply, long lasting, and less susceptible to blowing and fire than crop residues. Disadvantages include their competition for available nitrogen, their lowering of the pH, and the frequent packing of the finer materials. Chips, shavings, and millrun sawdust make good mulch, but the finer resaw sawdust packs tightly and may retard aeration and infiltration. Microorganisms carrying on decomposition of the highly cellulosic mulches (most are less than 0.2 percent nitrogen) compete with plant roots for available nitrogen.

Wood cellulose fiber and shredded paper are available commercially for use in several designs of hydroseeders and/or hydromulchers. The products are furnished in bales that are mixed with water to form a sticky paste and sprayed directly in place with specialized equipment. The dried slurry sticks together and forms an effective mulch at much lower application rates than required of nonslurried materials. Usually, seed and fertilizer are mixed directly into the same slurry so that seeding, fertilizing, and mulching are accomplished in a single operation. The low labor requirement and speed of hydroseeding makes it the method of choice in many large-area projects.

Bituminous Products

Petroleum-based products such as asphalt and resins are often suitable and are frequently used as mulching materials. Specially formulated emulsions of asphalt under various trade names have been used throughout the world to prevent erosion, reduce evaporation, promote seed germination, and warm the soil to advance the seeding date. The film clings to but does not penetrate deeply into the soil; it is not readily removed by wind and rain and remains effective from 4 to 10 weeks. Application rates of 1,000-1,200 gallons/acre are usually required to control erosion. Asphalt mulches cost about twice the applied cost of a straw mulch.

Asphalt emulsions are often used in conjunction with straw mulches to increase resistance to wind and water damage. Application rates are low so that the straw is merely cemented together without complete coverage by the asphalt.

Resin-in-water emulsions are often as effective as well-anchored straw as mulching materials. Resin emulsions are stable and can be diluted with large amounts of water without breaking the emulsion. The resins resist weathering by wind, rain, or soil bacteria and leave the soil surface permeable to water. Resin is usually applied at a rate of 600-800 gallons/acre, and costs are equivalent to those of asphalt emulsion.

Black asphalt absorbs solar energy and greatly increases the warming of soils at all times of the year. Germination and development are assisted in late fall and early spring, but in summer the absorbed heat can be lethal to young seedlings. Aluminized asphalt and white-pigmented resins have been developed to overcome these problems but have not found wide application.

Plastic Films

Plastic films are sometimes effectively used on very steep slopes or under other high-erosion conditions. The film is expensive, difficult to place, and very susceptible to wind damage. Seedling emergence must be monitored closely and the film ventilated or removed at the right time. Even 1 or 2 days of temperatures over 80°F is enough to kill most seedings. Often when the film must be removed, the seedling cover is not complete and serious erosion results.

Other Techniques

Other techniques can be useful under special circumstances or availability. Gravel and crushed rock have the advantage since they are permanent. A 1- to 2-inch layer of gravel will control surface erosion and vegetation development in the driest of areas. Gravel with a minimum diameter of 1/2 inch will resist winds to 85 miles/hour.

Manure is a mulch sometimes available at local feed lots. Manure acts as both a mulch and a slow-release fertilizer of fair quality but is not reliable in sustained erosion control as it tends to decompose rapidly.

Jute netting and woven thread-and-paper fabric are available commercially for stabilizing very steep or critical areas. These products are especially effective when used in conjunction with a straw or hay under-mulch; however, both are expensive and difficult to place, requiring insertion of several thousand wire staples per acre as anchors. Synthetic fabrics and netting designed to minimize erosion are becoming more and more popular for all high-priority applications (36).

Wattling is one of numerous special techniques that may be used to establish vegetation on vulnerable slopes. Tied bundles of flexible twigs are laid in furrows or trenches along contours, staked down, and partially covered with soil. Rows of wattles act to trap soil moving down the slope, to dissipate energy of soil and water movement, and to reduce effectively the slope of small areas immediately upslope. The areas between wattle rows are thus made favorable for establishment of vegetation. If the wattle is made of twigs such as willow that take root easily, the wattle itself becomes a part of the semipermanent or permanent stabilization system.

SECTION 9

PERIODIC INSPECTION

Provisions should be made in the plan of operation for periodic inspections and irregular visits usually continuing years beyond closure of the facility. Surface inspections and sampling, aerial photography, condition mapping, and subsurface monitoring are all forms of primary or supplemental inspection. Among key ingredients are provisions for assuring suitably experienced or trained inspectors.

GENERAL[1]

It is recommended that considerable time be spent on outlining appropriate weekly, monthly, and less frequent inspections. Emphasis should be placed on collecting data as well as being consistent and punctual. Field inspections are highly cost-effective and on that basis should appeal to and receive the enthusiastic support of the facility operator. Each inspection should be documented by written or graphical record. Figure 56 is an example. Monuments should be installed for survey control and point reference.

Observational parameters will be site-specific and may be distinct according to the combination of topography, climate, and ground-water conditions. Each site deserves its own inspection plan tailored to its particular characteristics. Among data that may be collected are those documenting the following:

a. Precipitates on ground surface.

b. Odors.

c. Intermittent seeps or soft spots as from shallow interflow.

d. Erosional effects.

e. Depressions and puddles.

f. Subsidence areas.

g. Vegetation stress.

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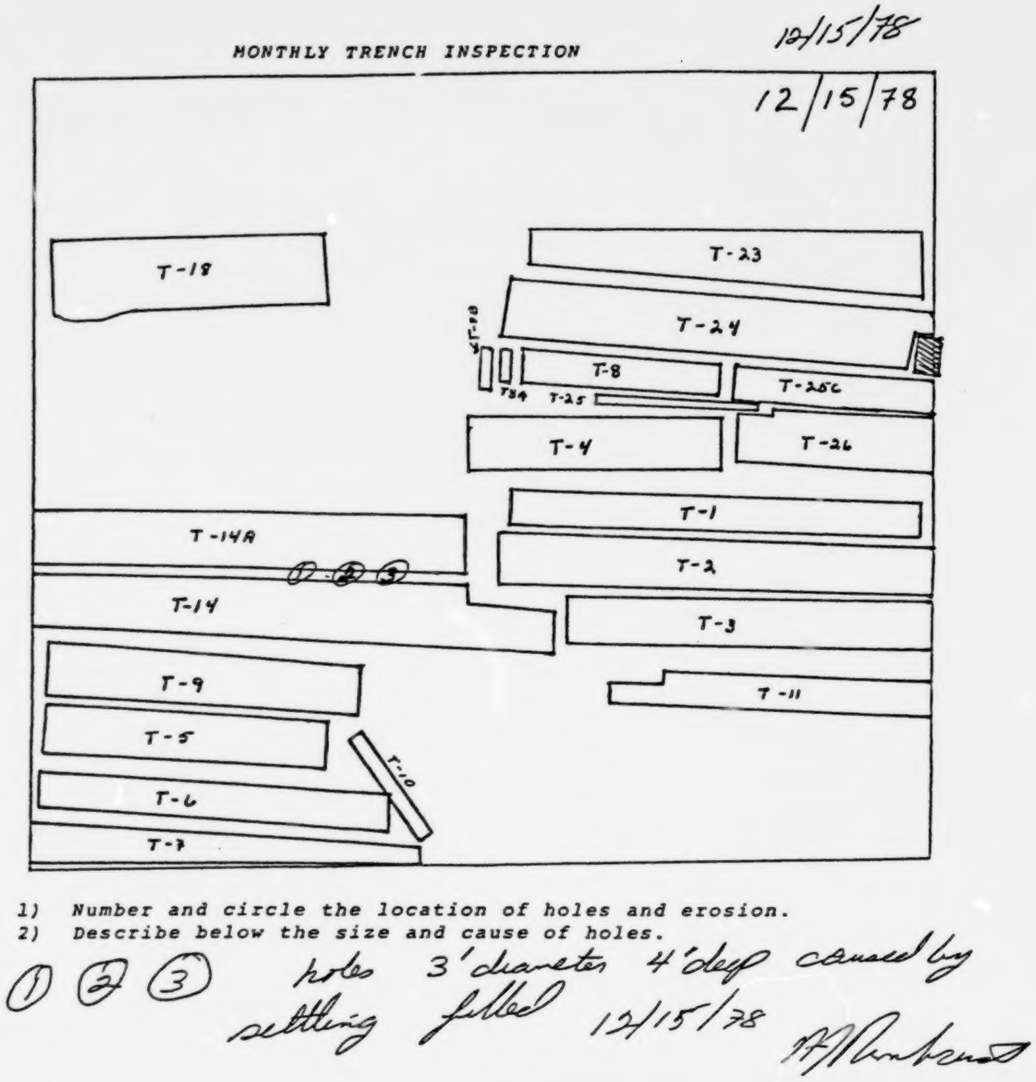
[1] These generalizations have also been discussed in the context of overall site monitoring (51).



MONTHLY TRENCH INSPECTION

12/15/78

12/15/78

T-18
T-23
T-24
T-8
T-25C
T-34
T-25
T-4
T-26
T-1
T-14A
T-2
① ② ③
T-14
T-3
T-9
T-11
T-5
T-10
T-6
T-7

1) Number and circle the location of holes and erosion.
2) Describe below the size and cause of holes.

① ② ③ holes 3' diameter 4' deep caused by settling filled 12/15/78

Figure 56. Example inspection report for Sheffield LLRW facility.

h. Undesirable species of vegetation.

i. Animal burrows and mounds.

Among these, a through c directly monitor for migrating pollutants or their precursors, and d through i have peripheral functions in combination with site maintenance.

Other monitoring tasks such as sampling can be combined with the field inspection to provide continuity. The degree of success depends upon the ability of the inspector to interpret the situation and the amount of time available for the study. Ample time must be provided. Timing may also be critical as for locating seeps after a heavy rainstorm.

The inspector should have a detailed map or aerial photograph of the entire site including sufficient markers and survey monuments to facilitate location of ground positions. For convenience, the base map may be in several sheets. While traversing the immediate site and the surrounding acreage, the inspector should record findings on the map and give an overall picture that can be easily interpreted. Provided the inspections are made frequently, they may allow the quickest response to developing problems.

Seeps can be useful sources of information or sampling points; however, according to good engineering practice, seeps will be rare at waste sites. Also, experience with landfill leachate has shown that seeps are often highly variable in activity in relation to location and the period of time (52). When there are substantial changes in seep locations or flow rates or when new seeps suddenly appear, a change in the flow system may be indicated. The nature and cause of the change, however, may have to be explained by a subsurface investigation.

Contamination of ground water or generation of gas may result in stress and possible destruction of vegetation. Such stresses affect agricultural crops, stands of trees, and marsh or meadow vegetation. In marsh environments the condition of vegetation can serve as a monitoring device observable directly or by remote sensing; however, new waste facilities will seldom if ever be sited in or adjacent to marshes.

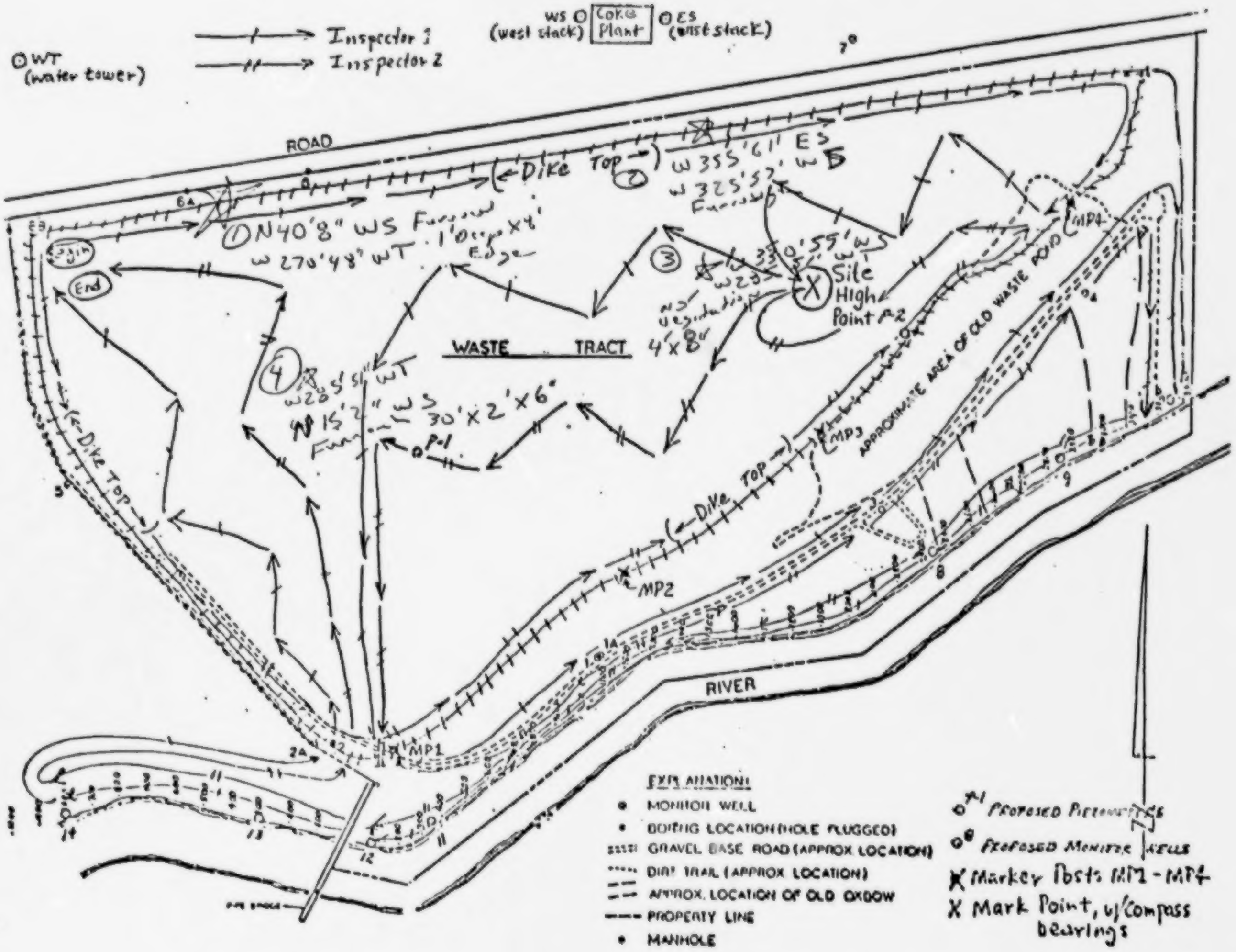
Crops and trees generally grow in areas with a water table at intermediate depth and are occasionally stressed by gases or through contaminant uptake. Some agricultural crops, including fruit orchards, have been destroyed by migrating gases generated within a nearby landfill and subtle stresses placed upon these species may be detectable by field inspections.

While identifying the precise cause and mechanism of stress can be prohibitively costly, it may be possible to relate the stress to a general cause which may in turn be related to the presence of the disposal facility. Mapping the extent of stressed vegetation may provide an indication of the extent of the total impact on the surrounding environment.

SURFACE INSPECTION

The cover system should be inspected at an appropriate interval by traversing the cover on foot and making appropriate notes and photographic records. The traverse may be established and continued in several ways. A different path may be followed each visit or the same permanently established route may be repeated. Inspections along variable traverses provide a total picture but are not so conducive to recording subtle changes in individual features on the cover.

Figure 57 shows an inspection traverse for one actual cover system. This traverse was developed as appropriate in discussions between regulators and the owner of the previously uncontrolled hazardous waste site. One of the



WT (water tower)
Inspector 1
Inspector 2
WS (west stack)
Coke Plant
ES (east stack)
ROAD
(←Dike Top→)
②
W 355'61' ES
W 325'57' WS
Furrow
① N40'8" WS Furrow
W 270'48" WT 1' Deep x 8'
Edge
③
W 23
35° 0'55' WS
35' WT
No vegetation
4'x8'
Site High Point P-2
WASTE TRACT
④
W 28'5'51" WT
N 15'2" WS
Furrow
30'x2'x6"
P-1
Begin
End
(←Dike Top→)
(←Dike Top→)
MP1
MP2
MP3
MP4
APPROXIMATE AREA OF OLD WASTE POND
RIVER
6A
2A
8
9
11
12
13
14
EXPLANATION
MONITOR WELL
BORING LOCATION (HOLE PLUGGED)
GRAVEL BASE ROAD (APPROX LOCATION)
DIRT TRAIL (APPROX LOCATION)
APPROX. LOCATION OF OLD OXBOW
PROPERTY LINE
MANHOLE
P-1 Proposed Piezometers
8 Proposed Monitor Wells
Marker Posts MP1 - MP4
X Mark Point, w/Compass bearings

Figure 57. Inspection traverse at covered waste site.

last modifications to the inspection plan concerned the position of major turning points along the traverse. It was recommended that appropriate points be surveyed and marked permanently for ease of relocation even in high grass. By zigzagging across the traverse line, the inspector can observe and document a representative strip perhaps 100 feet wide.

Provisions may need to be made for regular examination of specific features along a traverse. Features such as eroded banks, patches of dead vegetation, and exposed membranes should be reexamined during each inspection. The position of such a feature can be located by triangulation provided there are permanent surveyed points nearby. Representative vertical aerial photographs or detailed topographic maps, where available, will facilitate location of points.

SETTLEMENT MONITORING

Settlement plates should be established on the completed cover and monitored by surveying periodically. The points may be concentrated along one or a few profiles representative of the cover. Preferred orientations and superimposed positions of waste cells should be considered carefully to avoid missing differential settlements developing over short distances. For example, in Figure 30 one would expect any differential settlement to be concentrated beside the superimposed soil dikes. Accordingly, settlement plates should be placed over the superimposed dikes as well as over the adjacent superimposed waste cells. Plates should be installed for permanence and with appropriate protection from vandalism and accidental disturbance. Concrete bases 2 feet or more in diameter are suggested.

Surveys should be repeated every few years until settlement behavior is established. An interval of 10 years should be sufficient subsequently to recognize any deterioration beginning sometime in the distant future.

AERIAL INSPECTION

Aerial photographs are particularly cost-effective for documenting the condition of the surface of a cover system. There are no other reasonable means of recording the details and extent of a developing erosion system from ubiquitous rivelets converging downslope to trunk gullies. A set of such photographs over a period of time documents the rate at which the system is developing and indicates the ultimate effect on the cover system. Oblique aerial photographs may adequately reveal and document the condition of the cover for substantially less cost than vertical photographs. With that cost advantage, it may be possible to photograph the cover more frequently.

It is necessary to obtain more than one oblique view at each visit so that information is not missed in blind spots. Color photographs are usually preferred over black and white. It is particularly important to coordinate the site visit and photography so as to minimize apparent differences resulting primarily from different stages of growth of the vegetation. With color photography, one might choose to photograph the cover annually a certain number of days or weeks after emergence of new growth in the spring. This would tend to provide a contrast between healthy green areas and lagging or unhealthy areas still colored brown.

CONDITION MAPPING

One of the most sophisticated plans for periodic inspection of the cover consists of a complete mapping of one or more important characteristics over the entire surface area. This procedure requires an aerial photograph or detailed base map upon which to plot the observations. Variations in vegetation may already be evident in aerial photographs, and an examination on the ground provides the opportunity to verify inferred conditions and to fill in any questionable areas. Points or linear features can be located and areas of uniform characteristics outlined directly on the map or photographs or on overlay sheets. This information can be transferred to a clean office map; but in any case, the field sheets should remain as a part of the file of post-closure history.

SAMPLING AND TESTING

The cover inspection techniques described above concentrate on conditions visible on the surface or from the air. To evaluate the condition of the cover system below the ground surface, test pits and other means of sampling or observing the subsurface condition are needed. An experienced engineer should supervise pit excavation and sampling. Provisions in the maintenance plan or contract should specify frequency and approximate locations for sampling and observation of the subsurface. It is possible to retain considerable flexibility in these specifics by presenting guidance in general terms. If inspection pits are needed and are not in violation of RCRA regulations, it might be reasonable to require annual inspection through the cover (or to the impermeable membrane) at points determined randomly or according to possible problems visible at the surface. For example, one test pit might explore the subsurface where sparsity of vegetation indicates droughty or otherwise anomalous conditions.

Very specific directions should be included on effective backfilling of any test pits or borings. For relatively small borings, the procedure might consist of backfilling with clay from the full depth of penetration. Appropriate backfilling for test pits and other large excavations through the cover deserve careful attention to assure that the backfill or its interface with the undisturbed cover system has not created a new problem. Conceivably a plug formed by backfilling a test pit located in a topographic depression can leak surface water through the cover system if the plug soil is permeable and the barrier element is not properly restored.

One of the best methods of neutralizing this potential problem is by backfilling the test pit with the original material types layer by layer. This procedure tends to preclude the introduction of any anomalies of flow paths caused by anomalies in hydraulic head or coefficient of permeability. Possibly, excessive costs of such a backfilling procedure would need to be weighed against expected effectiveness and overall results.

The number of penetrations for observation or sampling should be held to a reasonable minimum. This constraint throws an additional burden on the sampling plan to obtain complete and accurate information at the relatively few points sampled. Sample disturbance should be avoided, and the in situ condition should be preserved or observed quickly. Jar samples from progressively deeper levels provide a moisture profile at the time of sampling. Where the primary purpose is for observation of the condition of the cover, the pit must be of such dimensions to allow the observer an appropriate view and working space. Observations should be recorded in such a way as to show clearly the important characteristics of each layer or increment thereof. A graphical portrayal of the profile usually constitutes an important part. A plan map of abrasions, seams, and deformations in a membrane is also important documentation. Where samples are to be recovered, the method should be prescribed and preferably will come from a widely recognized source such as the collection of ASTM standards and recommended procedures. In the case of recovery of block soil samples from pits, the emphasis should be placed on rapid recovery and preservation of in situ water content by an appropriate method such as waxing.

GROUND-WATER MONITORING

The effectiveness of the cover system is sometimes reflected in a subtle way in the results of ground-water monitoring. A monitoring program will be operational at many sites, particularly as required of RCRA facilities (Subpart F of 40 CFR 264), and will provide an available source of information supplementing the inspection program specific to the cover. It is recommended that measures for utilizing the ground-water monitoring program be specifically outlined as a part of inspection of the cover system. Without a formal coordination in the inspection plan, the subtle interrelationship is easily overlooked.

The importance of the ground-water monitoring system is highly influenced by specific site and hydrogeological conditions. A site located well above the water table and in which most of the potential water flow is directly downward from the ground surface is most likely to show a direct correspondence between leachate migration and cover leakage. The most direct monitoring in this case is in the leachate collection system. Any increase in the volume of leachate not clearly correlated with a previously established background or seasonal cycle would suggest a deterioration in cover performance.

SECTION 10

MAINTENANCE AND REPAIR

Maintenance of cover integrity and effectiveness is required by 40 CFR 264 (Table 8). A maintenance program can accumulate substantial costs over the intermediate term yet still continue to be burdensome where inadequate provisions are made for finding and correcting problems (Table 25). Therefore, it is recommended that the program be scheduled with a concentration of effort on the front end, so that problems can be recognized soon and adjustments can be made. As improvements are made and the understanding of the facility and its environment grows, the cover system should become stabilized, and the maintenance expenditures should become moderate. Conversely, cost may escalate if important processes are overlooked.

PERIODIC GROOMING

A category of maintenance (53) needs to be recognized short of cover repair. There will be certain types of work to be accomplished on the cover periodically and generally, particularly for the first few years after closure.

TABLE 25. POSSIBLE FUTURE PROBLEMS

Chronic erosion	Chronic vegetation failure
Erosion event	Vegetation failure event
Inadequate drainage system	Frost disturbance
Slope creeping	Wind erosion
Slope sliding	Cracking
Subsidence	Plugging of porous soil
Differential settlement	Deterioration of synthetics
Flooding	Loss of locations and monuments

Maintenance of Vegetation

Where vegetation is established on the cover system, at least a minimum amount of maintenance is necessary. Judicious twice-yearly mowing will suppress weed and brush species. Annual fertilization (and liming if necessary) will generally allow desirable species to out-compete the lower quality weedy species. Occasional use of selective herbicides usually controls noxious invaders, but care must be taken to avoid injuring or weakening the desirable species, lest more harm than benefit will result in the long run. In rare circumstances, large insect populations may threaten the stand of vegetation so that insecticide application becomes desirable.

Provisions should be made for the eventuality of a favorable transition from the originally established plant community to another of greater compatibility with the site environment. Such a change may even be part of a long-range strategy for vegetating the cover system. This strategy is a logical extension of that according to which ryegrass is planted for rapid stabilization with the intention that the ryegrass be only temporary, and perennial grass will ultimately prevail. The planning of a long-term succession of plants and the proper maintenance for accomplishment of the objective could profitably occupy the designer in considerable effort. Often the plants that are native to the region are targeted as ultimate occupants, but even then problems may arise. For example, native tumbleweed has been a problem at dry disposal sites since its roots can descend as far as 20 feet and into disposal units.

Reconditioning of Soil

Chronically weak and vulnerable vegetation sometimes signals a need for a revitalization of a vegetative soil layer. The characteristics of possible concern are:

a. Texture.

b. Water-holding properties and drainage.

c. Nutrient content.

d. Accumulations of gases.

e. Accumulations of toxic salts.

The guidance under MANIPULATING SOIL FACTORS (SECTION 8) is directly applicable.

REPAIRS

Cover repairs may be defined for purposes of this document as any work undertaken after completion and acceptance of the cover system for the purpose of returning a defective portion of the system to an acceptable condition. Major repairs can be distinguished from minor repairs as a matter of degree.

Provisions should be made for both categories since both can reasonably be expected over the life of the facility.

General

Minor repairs, which may be thought of as patching, categorically include inexpensive repairs that can be accomplished in a short time by operational or caretaker staff. Repairs of this nature are simply to return the cover to its original condition. Minor patching repairs are probably most commonly needed to take care of damage accumulating slowly over a long period of time.

There is usually a need for a category of repairs involving some modification of the original cover system. These major repairs often incur greater costs, although their tendency to be concentrated or highly localized helps to moderate the total cost. A very common type of major repair addresses a developing erosion problem as it arises unexpectedly during infrequent excessively heavy storms.

Ordinarily it would be difficult to anticipate the problems and have a repair work unit ready for a solution. The design of the cover system was originally targeted on that combination of layering, surface configuration, and other characteristics promising longevity and a minimum of problems. Accordingly, the maintenance plans should provide contingencies for possible future problems of a large variety. Certain generalized provisions can be in place for accomplishing repairs that might conceivably be needed. It is also important that the assignment of responsibility for repairs and the identification of funding source or sources be given. Beyond this, it is appropriate to be aware of the possible scope and timing of future problems and their solutions. Information of this nature is given in the next subsection.

Maintenance contracts should be carefully prepared for both large and small repair needs. The maintenance contract at one old corrected site contained minimums on payment which encouraged the contractor to accumulate maintenance and repair needs before acting. Excavation and replacement of a small volume of contaminated surface soil as a means of monitoring leachate was delayed.

Problems and Solutions

On the basis of the problems observed on cover systems to date, it is anticipated that a relatively few broad types will encompass most problems developing in the future. In turn, it has also been observed that required repairs are usually localized. Therefore, it should be possible to foresee the possible repair work at the design stage and to make some provisions in planning for deterioration that is most likely to occur over a long period of time.

Gully development--

The most common problem on portions of cover systems with slope exceeding five percent is a development of large or small gullies early in an erosion cycle. The cover system is especially susceptible to gullying when it has no vegetation, so gully erosion processes have an advantage in the interval before vegetation has first been established. Gullying continues to threaten, however, into the long term. Even such subtleties as the ruts from maintenance vehicles are capable of starting the gullying process.

A dendritic pattern of tributary gullies converging on the deepest stem gully can develop on waste cover surfaces that are irregularly configured in harmony with the natural terrain (Figure 58). The cover in the figure includes a synthetic membrane below soil. On the other hand a planar slope, as is commonly established along the side of a cover system, will be more likely to have a linear arrangement of gullies trending parallel down the slope with only a minimum of convergence into larger channels (Figure 59).

Gully erosion can involve subsurface water flow as well as surface erosion. The contribution of subsurface flow is most dramatic where an impermeable membrane has been emplaced at relatively shallow depth, as in many RCRA covers. Clearly the quantity of water that infiltrates can soon reach the storage capacity of the soil. Within a granular soil of relatively high permeability, the perched water flows relatively rapidly along any elevation gradients. Shallow laterally flowing water can emerge as seeps and substantially aggravate the surface erosion condition.

Gullies can be removed by grading to a smoother V-shaped cross section followed by establishment of turf. One potentially serious drawback of this remedy is that the grading operation may detrimentally affect the original cover design. For example, blading the sides of a gully to a V cross section will substantially reduce the thickness of the top layer, particularly along the gully axis. Operation of equipment along the gully may also have adverse effects on the system through flexure and cracking and by rutting and offset under the wheels.

One method of gully repair that is recommended for consideration is backfilling to the original grade with stone of narrow size range (41). The same gradation as recommended for drainage layers may be considered. Optimum results would probably be obtained with stone of the following coarse characteristics:

Sieve Size, in.	Weight Percent Passing
5	95
3	75
1	0

This cobbly material has a very high coefficient of permeability, yet its voids are sufficiently small to prevent turbulent water flow.

By filling gullies with free-draining stone, one may be able to convert a detrimental condition into an asset. The well developed system of converging gullies is highly efficient in drainage and in its response to changes in the site environment, but when stabilized with free draining gravel, the filled gullies become a permanent system for expedient drainage of the slopes.

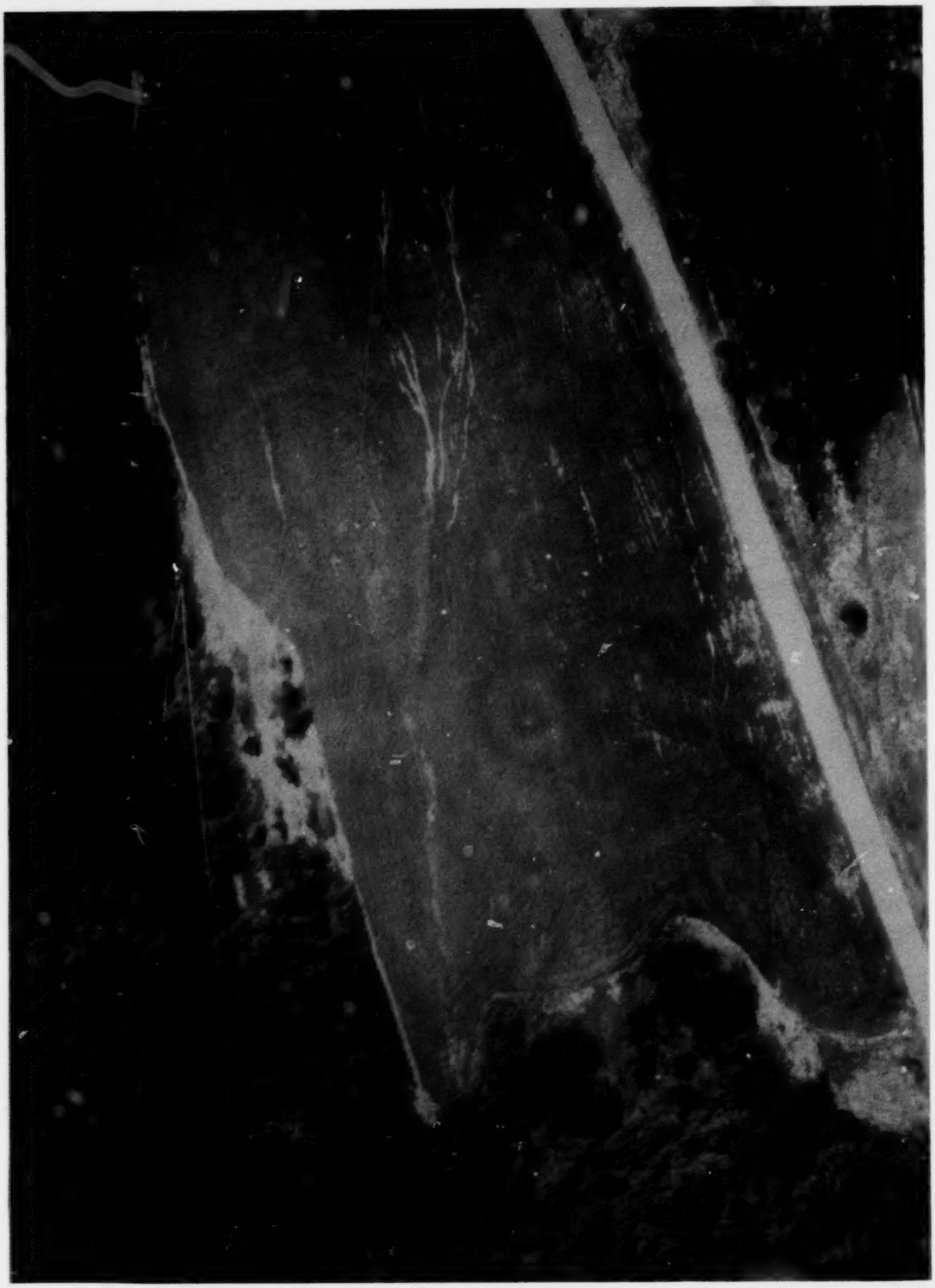


Figure 58. Erosion gullies on recently completed cover system at Ft Drum.

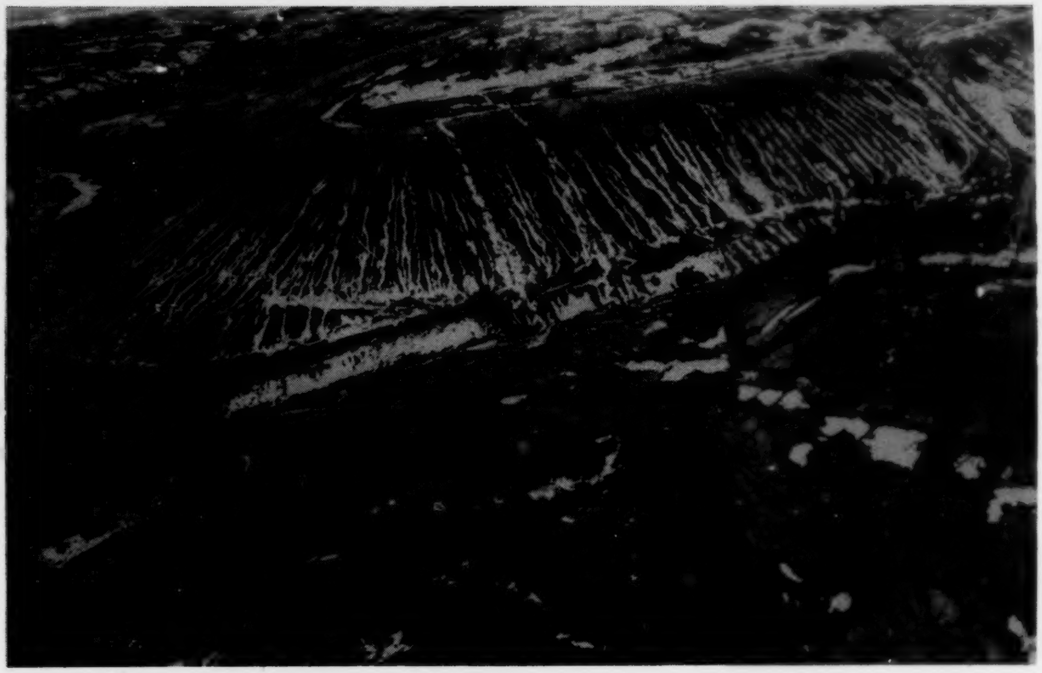


Figure 59. Erosion gullies on regular slope on Kin-Buc landfill.

A fabric or some other boundary feature acting as a filter will probably be a necessary supplement to the gravel filling. The fabric serves to exclude the fine particles of the surrounding soil, which otherwise would tend to wash into and accumulate in the openwork gravel, eventually reducing its effectiveness.

Subsidence--

Cover systems over porous types of waste continue to be vulnerable to deterioration by the formation of subsidence holes during the long term. Subsidence may be manifested as a stepwise dropping of a roughly circular or elliptical area generally no more than a few meters across or may be manifested as a more subtle low spot where puddling tends to occur. To some extent, which of these forms is found depends upon the nature of the cover system. A cover including dense and therefore strong cohesive soils will sometimes temporarily bridge across a void forming below. This style of subsidence usually culminates in sudden formation of a deep offset. The less dramatic, gradual type of settlement is sometimes more serious because it tends to affect a larger area. Small but significant lows facilitating infiltration of water can even form as ruts from operation of maintenance vehicles (40).

Procedures for repairing settlement or subsidence depressions are fairly straightforward. The hole is usually filled with additional cover soil from the stockpile, but some rather extensive repairs and reconstructions may be needed for deformed or torn synthetic membranes. It is recommended that techniques of keying, material matching, patching, and mending of aged synthetics be used in repairing depressed cover areas. These recommendations are not based on past experience, but instead are anticipated to be cost-effective for achieving the simple objective of restored layer continuity.

Slope instability--

On side slopes, particularly where they exceed 25 percent inclination, there is usually a potential for slippage of entire sections of material laterally or down the slope. Sometimes the process is combined with gully erosion and manifested as mud flowage. Aggravating conditions include a high degree of saturation such as might arise from concentration of subsurface seepage or from thawing of frozen ground.

Since the disruption caused by slope instability is at least locally quite serious, a partial reconstruction of the cover is usually needed. Reconstruction is discussed in the next subsection. Addition of a berm along the base of the slope is one option that is frequently effective.

Defective drainage system--

Occasionally a cover system will be constructed with defective drainage. Some likely deficiencies evident in past experience are lack of diversion from the crest of the slope and vulnerable bends or knickpoints along the channels. Also the lined portions of drainage channels are sometimes found to be vulnerable to erosion or insufficient in capacity. Elsewhere a need may become apparent for such special drainage features as culverts, drop inlets, and catch basins.

A number of techniques are available for repairing deficient drainage systems. The possibilities for unexpected erosion can certainly be anticipated, and therefore, provisions for repairing erosion damage along the channels are deserving of considerable attention. Straightforward techniques that are available include modification of channel alignment and installation of a lining feature or control structure.

Placement of stone armor in channels is an effective technique for reducing erosion since the stone disrupts water flow as well as covering the vulnerable soil. Long-term remedies are usually preferable so the choice of maintenance personnel has frequently been to manipulate the vegetation plan for beneficial effects.

Leakage spots--

Upward or lateral leakage of gases and capillary water from the disposal unit into the cover system has occasionally aroused serious concern in the past. Although cover systems can be designed to control migrating gas and many hazardous wastes present no gas-generation potential, a contingency for such a problem should be incorporated in the overall facility plan. Similarly, the capillary rise of contaminated water to the ground surface with deposition of salts at or near the surface is not a very likely threat, particularly for RCRA covers, but nevertheless deserves careful consideration. Plans for replacing and repairing contaminated areas of the cover system should be formulated at least in general terms. Unlike the repairs undertaken for other types of problems, repairs for chemical damage to the cover system may have to be preceded by a careful delineation of the problem area based on field testing. Such preliminary work adds an increment of cost.

Leakage problems may be corrected by an upgrading of a gas drainage system where one exists already. Where a drainage system is not in place already, gravel drains and buried pipes may be retrofitted, but special care will be needed to ensure that they are compatible with the rest of the cover system. For example, a French drain or gravel drain for conveying gas can also convey water downward through the cover if not properly capped with impermeable clay.

RECONSTRUCTION

All or a portion of the cover system may need to be reconstructed where damaged by environmental processes such as slope instability or where shown to be ineffective in performing its primary function. Since the necessity for reconstruction indicates a serious problem and therefore a deficiency in the original design, a new design is frequently necessary. Accordingly, new plans and specifications may be developed for entering into another contract.

A cover may be reconstructed to correct some of the following deficiencies:

a. Drainage channels persistently susceptible to erosion.

b. Side slopes experiencing instability.

c. Barrier layer or other critical element of the cover system showing signs of deterioration.

Deterioration of the barrier layer, e.g., by cracking or long-term and pervasive penetration by roots, is especially threatening. Such effects can come about through a relatively subtle misjudgment in cover design, e.g., an insufficient burial depth. Swampy or droughty areas of substantial size may warrant reconstruction, whereas correction of the same problem on a smaller scale is considered only repair work and accomplished on a less formal basis.

CONTINGENCY PLAN[1]

Problems likely to develop in the distant future are difficult to anticipate at a preliminary stage or even when the cover system is designed and the contract documents prepared. Confidence in the cover system is implicit in the design. The whole purpose of the design process is to plan a cover system that will be effective over a long period of time. On the other hand, the expectation that any cover system will serve effectively through a design life as long as hundreds of years is speculative. With that frame of mind, the designer should be motivated to outline contingencies for repairing specific future problems. Table 25 presents a list of possible future problems, but the specifics of an individual site and its environment may suggest others as well. Visits should be made to existing sites of similarly disturbed land to observe conditions and problems.

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[1] Contingency plan here refers generally to a technical plan, not necessarily a part of the contingency plan required in Subpart D of 40 CFR 264.

Once the general types of problems are recognized, it should be possible to pinpoint the areas in the cover system deserving extra attention. Erosion and instability are more common on steep slopes, and the gradient there serves as a rough index of the degree of vulnerability. Accordingly, contingencies there should place emphasis on the steep portions of slopes.

The next step in developing a contingency plan involves the examination of the degrading process itself. The designer may want to review the extensive literature on erosion and instability processes from the viewpoint of empiricism more than theory. At the minimum, the designer will need expertise or documentation on geomorphic processes at the relatively small scale of a cover system. In the past there has been a serious tendency to ignore long-term deterioration of landfills and to assume that once vegetation has been established, a landfill is satisfactorily closed.

Where the review of geomorphic processes suggests that specific small areas may deteriorate in the future, a rough plan of action should be developed. The plan should be accompanied by an estimate of cost in terms of unit costs in the present year. There is at present one school of opinion that a clear understanding of the large total cost of waste disposal including indirect costs from the impact on the environment will eventually reduce the volume of wastes by forcing improvements in industrial processes. It can hardly be argued that reasonable change in industrial processes and in product demand among the public is not a positive change, and therefore the designer of the cover system can exert a positive influence even beyond his immediate objective through a careful and thorough estimation of the costs of future reconstruction.

A plan for possible future cover reconstruction cannot extend much beyond the generalizations on vulnerable locations, deterioration processes, and future costs. Other than including a provision for funding all reasonably expectable work needs, there is little tangible to be said. The actual plan of work will be formulated as the need arises and will be accomplished, more or less, as a new job in site restoration. The big advantages will lie in the immense amount of useful technical background data on the site if the site has been designed, constructed, and maintained according to guidance in this document.

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APPENDIX A

SPECIFICATIONS FOR CONSTRUCTION OF COVER SYSTEMS

This appendix presents specifications that are generally suitable for construction of cover systems. The specifications and the four cover designs to which the specifications are applied should not be regarded as having official status with EPA. In fact, some of the features do not satisfy RCRA as of 1986. These specifications should, however, illustrate to writers and reviewers of specifications the state of the art, with its characteristic language and necessary thoroughness.

Only technical provisions are considered here. The general provisions and other parts and sections of the contract primarily prescribing legal, regulatory, and financial arrangements are not included.

PLANS AND DRAWINGS

Plans prepared by the owner as a part of the contract are almost always a necessary adjunct to specifications for representing dimensions, positions, and areal configurations as well as requirements amenable to tabulation. One should think in terms of "Plans and Specifications." Plans are unique to each job and therefore are not addressed in this appendix, but a brief review of the content of a set of plans is given in Table 13 and accompanying text of Section 3 on pages 35 and 38. Frequent references to plans are found in the specifications, reaffirming their primary importance.

Working drawings are commonly required of construction contractors. Working drawings show structures or features necessary for adequate control of the work. Examples are working drawings showing the sequence of construction and the access routes for haulage and placement of cover materials. Possible problems or problem locations are sometimes foreseen from such drawings.

ORGANIZATION OF SPECIFICATIONS

Specifications are organized for clarity in achievement of the intended design. This organization includes the addressing of each major construction task in a separate part (Table 12 on page 36). Materials and equipment are sometimes addressed in separate parts, but elsewhere are addressed under each construction task. Some versions of specifications leave the choice of equipment and some materials with the contractor and largely excluded from the specifications.

The example outline of technical provisions for covers in Table 12 is organized much like that developed for use of state highway departments (13).

The similarity between a cover system on backfilled solid waste and a pavement system on an embankment subgrade is sufficient to suggest that highway specifications are usable models needing only careful modification. Also, the vast experience available in highway departments in every state is potentially useful. To apply the highway model, a few parameters are equated as indicated in Figure 13 on page 31.

It should be understood that some parts or sections will not always be needed. The outline in the table is quite broad and even suited to contracts for remedial cover at problem waste sites. For remedial work Section 201 on clearing and grubbing and 202 on removing obstructions might need careful detailing. Similarly, the preparation of the subgrade may amount to modifying and supplementing the existing surface soil and be detailed sufficiently under Section 205 (Table 12). Elsewhere, the subgrade may be entirely new and deserving of elevated status in the design and construction effort and, therefore, might be allotted a lengthy Section 204 in the specifications, e.g., when a covering contract follows closely after filling of the waste cell.

Where the covering work is one portion of a contract for the whole disposal operation, the parts and sections applying to cover will be integrated into a more comprehensive set of specifications. Advantages and disadvantages of contracting the cover system alone constitute a separate subject, beyond the scope of this appendix. The size of the contract is, nevertheless, always deserving of careful consideration.

Details of Sections 204 and 205 and selected sections of Parts 300 through 700 are given below as applied to specific cover designs. Other parts and sections can be similarly modified from existing sets of specifications, e.g., from AASHTO (13).

SPECIFICATIONS FOR COVER DESIGN I

The following selected guide specifications might be suitable for contracting for construction of Design I identified as S/C/L-1 under EXAMPLE DESIGNS (See page 38). Section numbering is conformable to the organization of technical provisions in Table 12 on page 36.

* * * (Note)

204 BACKFILL AND EMBANKMENT

(Note)

204.01 Description. This work shall consist of constructing embankments, including preparation of the foundation area; constructing dikes within or outside the disposal cell area; placing and compacting approved material

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Note: The triple asterisk symbol (***) indicates omission of portions of the specifications concerning other than cover construction.

Note: Where the cover system is to be placed on preexistent foundations such as old backfill and intermediate cover, 205 SUBGRADE PREPARATION may be substituted for section 204. (See BUFFER LAYER AND FOUNDATION, page 62).

within waste cell areas where unsuitable material has been removed; and placing and compacting material in gullies, pits, and other depressions below the subgrade.

204.02 Materials. Only materials identified on the plans or otherwise approved by the Engineer shall be used in the construction of embankment and backfill.

204.03 Keying Methods. Unless shown otherwise on the plans or special provisions, all sod and vegetable matter shall be removed from the surface upon which embankment is to be placed, and the cleared surface shall be completely broken by plowing, scarifying, or stepping to a minimum depth of 6 inches. This area shall then be compacted to the same density required for the embankment. Sod not to be removed shall be thoroughly disked before construction of embankment.

When embankment is to be placed on an existing hillside that is steeper than 6 horizontal on 1 vertical, the slope shall be continuously benched in not less than 12-inch rises as the work is brought up in lifts. Each bench shall begin at the intersection of the ground line and the vertical side of the previous bench and shall be of sufficient width to permit placing and compacting operations. Existing slopes shall also be stepped to prevent any wedging action of the embankment against structures. No direct payment will be made for the material thus cut out nor for its compaction along with the new embankment material.

On newly constructed slopes, the bench keying shall be accomplished only where indicated on the plans.

204.04 Backfilling Around Structures. If embankment can be deposited on one side only of abutments, wing walls, or culvert headwalls, care shall be taken that compacting immediately adjacent to the structure will not cause overturning of or excessive pressure against the structure. When embankment is to be placed on both sides of a concrete wall, manhole, or box-type structure, operations shall be so conducted that the embankment is always at approximately the same elevation on both sides of the structure.

204.05 Placing and Compacting. Embankment shall be placed in lifts not exceeding 8 inches loose measurement and shall be compacted using compacting equipment before the next lift is placed. The Engineer may allow greater lift thickness providing proper density and uniformity are obtained. Effective spreading equipment shall be used on each lift to obtain uniform thickness prior to compacting. As the compaction of each layer progresses, continuous leveling and manipulating will be required to assure uniform density. Water shall be added or removed if necessary to facilitate compaction to the required density. Construction equipment shall be routed uniformly over the entire surface of each lift.

When the material consists predominantly of rock fragments of such size (Note)
that the material cannot be placed in lifts of the thickness prescribed
without crushing, pulverizing, or further breaking down the pieces resulting
from excavation methods, such material may be placed in the embankment in
lifts not exceeding in thickness the approximate average size of the larger
rocks, but not greater than ...... [2 feet suggested]. Each lift shall be (Note)
leveled and smoothed with suitable leveling equipment and by distribution of
spalls and finer fragments or soil. Where end dumping is employed, direct end
dumping upon the previously constructed lift of embankment will not be permitted. Rock shall be dumped on the lift being constructed and dozed ahead into
place. Rocky lifts shall not be constructed above an elevation 2 feet below
the finished subgrade.

Note: This paragraph should be removed in the common case where rock fragments constitute no more than a minor component.

Note: The dot underline symbol (.....) indicates the need for a decision on dimensions, etc. A suggested value may be given in parentheses [__].

204.06 Moisture and Density Control. The plans show the areas in which embankment shall be constructed with moisture and density control, and the distance below subgrade to which such methods shall be applied. All embankment down to 2 feet below subgrade shall be included. Construction lifts shall be no thicker than 6 inches after compaction.

Each lift shall be compacted to not less than ...... [95 percent suggested] of the maximum density. The material shall be dried or moistened uniformly before compaction, as necessary to bring moisture content to that appropriate for achieving required density.

Maximum densities shall be determined in accordance with ASTM D698. (Note) In-place field density shall be determined according to ASTM D1556, D2167, D2937, or D2922. The Contractor is responsible for testing but may use an approved commercial testing laboratory. All costs of sampling and testing shall be borne by the Contractor.

Density requirements will not apply to portions of embankments constructed of materials which cannot be tested in accordance with approved methods.

204.07 Compacting Without Moisture and Density Control. Embankment materials not designated for moisture and density control shall be deposited in lifts not exceeding 8 inches in thickness before compaction, unless otherwise specified by the Engineer. The acceptable types and application of compaction equipment are stipulated in the plans, however, other approved equipment may be used.

Dumping and rolling areas shall be kept separate, and no lift shall be covered by another until compaction complying with the requirements of this subsection is secured. Hauling and leveling equipment shall be routed and distributed over each lift of the fill in such a manner as to make use of compaction effort afforded thereby.

204.08 [Reserved] (Note)

204.09 Method of Measurement. (Note)

(a) Contract Quantity Payment. The quantities of backfill and embankment for which payment will be made are those shown in the contract for the various items, provided the project is constructed essentially to the lines and grades shown on the plans.

When the plans have been altered or when disagreement exists between the Contractor and the Engineer as to the accuracy of the plan quantities, either party shall have the right to request and cause the quantities involved to be measured again. When the quantities are measured for payment, the original cross sections plotted on the plans shall be used as original field cross sections. Additional original cross sections may be interpolated at points where necessary to determine the quantities accurately.

Note: The responsibility for testing in-place density lies with the contractor in this case. For other testing by an inspector representing the engineer, the wording would need revision.

Note: A subsection on Proof Rolling may be needed depending on circumstances. This addition may, in turn, necessitate another pay item in subsection 204.10.

Note: Lump-sum bidding and payment is often preferred over bidding and payment based on unit prices. A lump-sum price so bid is paid as full compensation for the estimated quantities shown in the contract.

(b) Measurement of Special Excavation. Measurements will be made for unsuitable existing materials actually excavated and removed to obtain proper compaction in the foundation for backfill and embankment. No measurement will be made of the suitable material temporarily removed and replaced to facilitate compaction of the material for the full depth shown on the plans.

Where it is impractical to measure excavated material by the cross-section method due to the erratic location of isolated deposits, acceptable methods involving three-dimensional measurements may be used.

(c) Measurement of Embankments. When specified in the contract, embankments will be measured and paid for in accordance with the terms set forth.

When payment for embankment constructed with moisture and density control is specified as a separate bid item, the volume so constructed will be computed in cubic yards by the Engineer from the dimensions of the embankment cross section and the depth below the completed subgrade to which this method of construction applies.

(d) Measurement of Subgrade Treatment. The work of stabilizing subgrade treatment areas will be measured by the square yard from the limits of the areas so treated. Correction of subgrade deficiencies, including those established by proof rolling, shall be incidental to embankment construction and not a pay item.

(e) Measurement of Water. When payment for water is specified in the contract, the water used in the work will be measured by the 1,000 gallons (M.G.) by means of calibrated tanks or distributors or by means of accurate water meters.

When water is not specified as a pay item in the contract, the water used will not be measured or paid for but will be incidental to the work.

204.10 Basis of Payment. The accepted quantities of Embankment (or Backfill) will be paid at the contract price for each of the pay items listed below that is included in the bid schedule. (Note)

Pay Item	Pay Unit
Embankment with Moisture Control	Cubic yard
Embankment without Moisture Control	Cubic yard
Special Excavation	Cubic yard or Ton
Water	M.G. (1,000 gallons)

* * *

205 SUBGRADE PREPARATION (Note)

205.01 Description. This work shall consist of shaping and compacting the subgrade prior to placing the lowest cover course thereon.

205.02 Construction Requirements. This work shall be done after any unstable sections of the subgrade have been repaired and after any existing material required to be removed has been removed.

Note: Lump-sum bidding and payment is often preferred over bidding and payment based on unit prices. A lump-sum price so bid is paid as full compensation for the estimated quantities shown in the contract.

Note: This section may be used in place of section 204 where existing backfill and embankment is largely adequate as a foundation for the cover system.

The Contractor shall compact and shape the subgrade for its full area as may be necessary to produce, at the time the lowest course is placed, the required density and stability in the top 6 inches of the subgrade and the required grade and cross section. The Contractor will be required to scarify, dry the material, or apply water as may be necessary to obtain the required density and stability. Unless otherwise provided in the contract, the "required density" shall be ...... [95 percent suggested] of maximum density.

The "required stability" shall be such that when any material for cover layers above is distributed on the subgrade, no rutting or displacement will occur. Rutting deformation traceable below the subgrade from any layer above shall be considered as indicating subgrade instability.

The "required grade and cross section" shall consist of a smooth subgrade surface conforming to the prescribed elevations for the particular subgrade being prepared, prior to constructing an additional course thereon. The prescribed elevation for any point on the subgrade surface where measurement is made shall be as determined from the grades staked by the Engineer and the typical sections shown in the plans.

In conjunction with the operations of subgrade preparation, the Contractor shall produce, load, and haul material of the same type as that used in the subgrade or in the course to be constructed where and in such amounts as the Engineer directs and incorporate such material into the subgrade. This work shall be at the appropriate contract prices for the material in place or, in the absence of such prices, regarded as extra work.

205.03 Method of Measurement. Subgrade preparation will be measured on an areal basis. Locations where grading or subgrade correction is required will not be included in these measurements but instead will be measured as extra work on a volume basis.

205.04 Basis of Payment. If the backfill, embankment, or intermediate cover being prepared was constructed under the same contract, the Contractor shall perform all work required herein at his own expense and without any direct compensation being made therefor. Payment for subgrade preparation as a separate item will be made only when the backfill, embankment, or intermediate cover being prepared was constructed under a previous contract.

Payment for Subgrade Preparation will be compensation in full for all costs of preparing the subgrade as specified, except that any expenses incurred in correcting unstable conditions below the top 6 inches will be compensated separately as extra work or at the contract prices for the equipment used if so provided in the contract.

Payment will be made under:

Pay Item	Pay Unit
Subgrade Preparation	Square yard
Subgrade Correction	Cubic yard

* * *

301 CLAY BARRIER

301.01 Description. This work shall consist of furnishing and placing a clay course on a prepared surface in accordance with these specifications, in reasonably close conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans.

301.02 Materials. The clay material in place in the course shall be homogeneous and shall meet the requirements of subsection 704.05. Either or both of two material categories may be utilized from the material sources:

(a) Homogeneous clay material, defined as clayey material having uniformity of grain size and mineralogical composition at the source deposit or in the material as delivered.

(b) Nonhomogeneous clay material, defined as clayey material from a source deposit or in the material as delivered having indications of stratification, weathering or soil forming effects, or other physical characteristics which will result in a combination of two or more soil types. Shortfall in estimated total volume of homogeneous clay material available from one source will be another basis for classifying material as nonhomogeneous.

The Contractor shall mix all nonhomogeneous clay material according to subsection 301.04 to achieve the requirements of the clay course. Use of both homogeneous and nonhomogeneous clay materials will be permitted, but their usage shall be separated by restriction to separate areas of the clay course approved in advance by the Engineer.

Homogeneous clay material will be accepted based on testing of samples representative of loads excavated at the source or delivered at the job site. Nonhomogeneous clay material mixed in a plant or by road-mix method will be accepted based on samples of the plant output or of combined windrows.

301.03 Preparation of Course Foundation. Before placing operations are begun, the area of the subgrade or course upon which the clay course is to be placed shall be cleaned and checked for condition and for conformance with the grades, lines, thicknesses, and typical sections shown on the plans or as ordered by the Engineer. When the clay course is superimposed within ...... [10 days suggested] upon subgrade or another course constructed under these specifications and that previous work has been accepted by the Engineer, the checking activity may be waived. (Note)

The subgrade and any preceding course shall be compact and suitable to support the construction and compaction equipment without settlement or displacement. Soft or yielding areas shall be corrected and made stable before the clay course is placed.

The foundation shall be tested for moisture condition and where found to be dry or wet of optimum moisture during original compaction by ...... [2 percentage points suggested where the foundation is sand] or more, it shall be examined for cracks, soft spots, and other defects and then shall be adjusted into the acceptable range by addition of water or by drying. The presence of defects may be cause for requiring replacement or repair of the foundation.

301.04 Mixing. The clay course shall be brought to a homogeneous condition rior to compaction. Unless otherwise specified, the Contractor shall mix nonhomogeneous clay material by one of the following methods:

(a) Stationary Plant Method. Before placement, nonhomogeneous clay material shall be mixed in an approved mixer. Addition of water shall be restricted to prevent balling and other problems preserving or increasing segregation of material components. Air pollution through the generation of dust shall be kept at levels permitted by State and Federal regulations. After mixing, the dry material shall be placed according to subsection 301.05.

(b) Travel Plant Method. After nonhomogeneous clay material for each lift of the clay course has been placed with a spreader or in windrows, the material shall be mixed uniformly by an approved traveling mixing plant. Water may be added to the extent that the addition does not result in balling or other interference with the mixing process. (Note)

(c) Road Mix Method. After nonhomogeneous clay material for each lift of the clay course has been placed with a spreader or in windrows, the material shall be mixed uniformly by motor grader or other (Note)

Note: In the case of Design I the foundation of the clay course consists of a sand course and underlying subgrade.

Note: Mixing in place may be unacceptable for Design I because of disrupting effects on the capillary barrier immediately below.

equipment approved by the Engineer until the mixture is uniform throughout. Water may be added to the extent that the addition does not result in balling or other interference with the mixing process.

In all cases of mixing and addition of water, the formation or preservation of balls or granules of unmixed components larger than ...... [1/4 inch suggested] across as spread and ready for compaction shall be avoided. The Contractor shall understand that such granules will be a basis for rejecting part or all of the clay course.

301.05 Placing and Spreading. Clay material for each lift of the clay course shall be placed and spread in such ways as to avoid damage to the previous lift or the course foundation. The Contractor shall understand that cracks, ruts, offsets, punctures, and other indications of damage to underlying material by equipment or procedures will constitute valid criteria for rejection and will necessitate replacement of damaged elements at the expense of the Contractor.

Where mixing is accomplished using travel plant or road mix methods according to subsection 301.04, such mixing shall be considered a part of placing and spreading.

The thickness of the loose lift shall be such as will meet the required compacted thickness specified in subsection 301.06.

301.06 Compacting. Loose lifts of clay material shall be compacted by equipment and procedures capable of attaining the prescribed density without damage to the lift being compacted or to underlying courses or lifts. Compactors that impart a kneading action or penetrate the top surface of the lift shall not be used unless approved by the Engineer. An appropriately sized tire roller compactor will usually be acceptable. The course shall be constructed in lifts not exceeding ...... [6 inches suggested], and lift thicknesses in multiple-lift courses shall be approximately equal.

The Contractor shall demonstrate the suitability of his proposed compactor unit for the material and course design by constructing a lift under similar conditions. This demonstration will normally be performed at the job site, but closely similar experience elsewhere may be substituted when approved by the Engineer. The bases for evaluating results will be the required in-place density and the indications of damage such as cracks, depressions, and shear surfaces.

The required density shall be ...... [90 percent suggested] of maximum density determined in accordance with ASTM D698. Compaction shall continue until a density not less than the required density has been achieved to the full depth of the lift.

The surface of each lift shall be maintained during the compaction operations in such a manner that a uniform texture is produced and any coarse component allowed under subsection 301.02 is firmly keyed. Water shall be uniformly applied over the materials during compaction in the amount necessary for proper compaction.

In-place field density shall be determined in accordance with ASTM D1556, D2167, D2937, or D2922. Modification of testing may be required to correct for coarse components. The Contractor is responsible for testing but may use an approved commercial testing laboratory. All costs of sampling and testing shall be borne by the Contractor.

301.07 Construction Joints and Surfaces. At the end of each day of construction a lateral construction joint shall be marked if not clearly evident. Temporary covering shall be provided if necessary to preserve the as-constructed condition intended. Upon resumption of work the joint shall be uncovered, cleaned, moistened, and scarified or trimmed back as deemed necessary to assure interlock along the joint when the lift is extended.

Course surfaces shall similarly be protected by temporary cover, to be removed completely upon resumption of work with addition of the course above. The Contractor shall drag, moisten, and scarify lightly the surface of a lift upon which another lift of the same course is to be constructed. The objective shall be to maximize the bonding between lifts without sacrificing integrity. On sloping courses this preparation shall follow contours.

301.08 Protection and Maintenance. The Contractor shall be required, within the limits of his contract, to maintain and protect the clay barrier in good condition and in a manner satisfactory to the Engineer from the start of work until all work has been completed and accepted. Maintenance by the Contractor shall include immediate repairs of any defects, regardless of cause, that may occur. This work shall be done by the Contractor at his own expense, and repeated as often as may be necessary to keep the course continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced for the full depth of the course by the Contractor at his own expense.

301.09 Method of Measurement. Clay course will be measured by the cubic yard in accordance with 109 MEASUREMENT AND PAYMENT. When specified as pay item, water added to the materials will be measured by the 1,000 gallons by means of calibrated tanks or distributors or by means of accurate water meters. (Note)

301.10 Basis of Payment. The accepted quantities of Clay Barrier, of the type specified, will be paid for at the contract price as follows:

Pay Item	Pay Unit
Clay Barrier Course	Cubic yard
Water for Clay Barrier Course	M.G. or Incidental to clay

* * *

403 FILTER LAYER

403.01 Description. This work shall consist of furnishing and placing a filter course on a prepared surface in accordance with these specifications, in reasonably close conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans.

403.02 Materials. The filter materials shall be homogeneous sand and shall meet the requirements of subsections 703.19 and 703.01. Material will be accepted based on test reports of samples representative of loads delivered.

403.03 Preparation of Course Foundation. Before placing operations are begun, the area of the subgrade or course upon which the sand course is to be placed shall be cleaned and checked for condition and for conformance with the grades, lines, thicknesses, and typical sections shown on the plans or as ordered by the Engineer. Where the sand course is superimposed within ...... [10 days suggested] upon subgrade or another course constructed under these specifications and that previous work has been accepted by the Engineer, the checking activity may be waived.

The subgrade and any preceding course shall be compact and suitable to support the construction and compaction equipment without settlement or displacement. Soft or yielding areas shall be corrected and made stable before the sand course is placed.

The foundation shall be tested for moisture condition and where found to be dry or wet of optimum moisture by ...... [4 percentage points suggested where foundation is clayey] or more, it shall be examined for cracks, soft spots, and other defects and then shall be adjusted into the acceptable range by addition of water or by drying. The presence of defects may be cause for requiring replacement or repair of the foundation.

403.04 Placing and Spreading. Sand material for each lift of the course shall be placed and spread in such ways as to avoid material segregation and mixing with or damage to the previous lift or the course foundation. The Contractor shall understand that segregations, mixtures, or cracks, ruts, offsets, punctures, and other indications of damage to underlying material by equipment or procedures will constitute valid criteria for rejection and will necessitate replacement of rejected elements at the expense of the Contractor.

Note: Section 109 MEASUREMENT AND PAYMENT is not included in this appendix.

The loose thickness of each lift shall be such as will meet the required compacted thickness specified in subsection 403.05.

403.05 Compacting. Loose lifts of sand material shall be compacted by equipment and procedures capable of attaining the prescribed density without damage to the lift being compacted or to the underlying material. Compactors that impart a kneading action or penetrate the top surface of the lift shall not be used unless approved by the Engineer. An appropriately sized tire-roller compactor will usually be acceptable.

The required density for compaction shall be ...... [85 percent suggested] of maximum relative density. The Contractor shall provide the maximum and minimum density parameters for the chosen sand material along with the calculated relative density required by this contract at least two weeks prior to placing sand material in the course. Details of the test methods shall be provided also. A method using a vibratory table is usually preferred for determination of maximum relative density.

The course shall be constructed in lifts not exceeding ...... [6 inches suggested] and lift thicknesses in multiple lift courses shall be approximately equal. Compaction shall continue until a density not less than the required density has been achieved to the full depth of the lift. Water shall be applied uniformly over the materials during compaction in the amount necessary for proper compaction.

In-place field density shall be determined in accordance with ASTM D1556, D2167, D2937, or D2922. The Contractor is responsible for testing but may use an approved commercial testing laboratory. All costs of sampling and testing shall be borne by the Contractor.

403.06 Construction Joints and Surfaces. At the end of each day of construction a lateral construction joint shall be marked if not clearly evident. Temporary covering may be required by the Engineer to preserve the as-constructed condition intended. Upon resumption of work the joint shall be uncovered and moistened as needed to assure interlock along the joint when the lift is extended.

Course surfaces shall similarly be protected by temporary cover, to be removed completely upon resumption of work with addition of the course above.

403.07 Protection and Maintenance. The Contractor shall be required to maintain and protect the filter layer in good condition and in a manner satisfactory to the Engineer from the time he first starts work until all work has been completed and accepted. Maintenance by the Contractor shall include immediate repairs of any defects, regardless of cause, that may occur. This work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the course continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced for the full depth of the course by the Contractor at his own expense.

403.08 Method of Measurement. Sand course will be measured by the cubic yard in accordance with 109 MEASUREMENT AND PAYMENT. When specified as pay item, water added to the materials will be measured by the 1,000 gallons by means of calibrated tanks or distributors or by means of accurate water meters.

403.09 Basis of Payment. The accepted quantities of Filter Layer, of the type specified, will be paid for at the contract price as follows:

Pay Item	Pay Unit
Filter Layer Course	Cubic yard
Water for Filter Layer Course	M.G. or Incidental to sand

* * *

406.01 Description. This work shall consist of furnishing and placing a vegetative soil layer on a prepared surface in accordance with these specifications in reasonably close conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans. The vegetative layer does not include vegetation.

406.02 Materials. Vegetative soil types shall be:

(a) Topsoil meeting the requirements of subsection 704.01.

(b) Loamy soil as defined by the US Department of Agriculture on the basis of grain size components and free of stones, roots, and debris over ...... [2 inches suggested] in greatest dimension. Up to ...... [8 percent suggested] gravel may be included and such gravel may be excluded as a grain-size component for purposes of calculating soil grain-size content.

Material will be accepted based on test reports on samples representative of loads delivered.

406.03 Preparation of Course Foundation. Before placing operations are begun, the area of the subgrade or course upon which the vegetative course is to be placed shall be cleaned and checked for condition and for conformance with the grades, lines, thicknesses, and typical sections shown on the plans or as ordered by the Engineer. Where the soil.course is superimposed within ...... [10 days suggested] upon subgrade or another course constructed under these specifications and that previous work has been accepted by the Engineer, the checking activity may be waived.

The foundation shall be compact and suitable to support the construction and compaction equipment without settlement or displacement. Soft or yielding foundation areas shall be corrected and made stable before the course is placed.

The foundation shall be tested for moisture condition and where found to be dry or wet of optimum moisture by ...... [4 percentage points suggested where foundation is clayey] or more, it shall be examined for cracks, soft spots, and other defects and then shall be adjusted into the acceptable range by addition of water or by drying. The presence of defects may be cause for requiring replacement or repair of the foundation.

406.04 Placing and Compacting Other Than Topsoil. Soil material for each lift of the vegetative course other than topsoil shall be placed and spread in such ways as to avoid material segregation and mixing with or damage to the previous lift or the course foundation. The Contractor shall understand that segregations or mixtures or cracks, ruts, offsets, punctures, and other indications of damage to underlying material by equipment or procedures will constitute valid criteria of damage and will necessitate replacement of damaged elements at the expense of the Contractor.

Loose lifts of soil material shall be compacted using a dozer or similar low-pressure unit and procedures capable of attaining the prescribed density without damage to the lift being compacted or to underlying material. The density after compaction shall be ...... [82-86 percent suggested] of maximum density determined in accordance with ASTM D698. In-place field density shall be determined in accordance with ASTM D1556, D2167, D2937, or D2922. The Contractor is responsible for testing but may use an approved commercial testing laboratory. All costs of sampling and testing shall be borne by the Contractor.

The course shall be constructed in lifts not exceeding ...... [8 inches suggested], and lift thicknesses in multiple lift courses shall be approximately equal.

406.05 Placing Topsoil. After being stripped from the source, the topsoil shall be placed immediately or stockpiled. Stockpiles shall contain not less than 200 cubic yards, shall have a height of at least 4 feet, and shall be trimmed to uniform surfaces and slopes. The Contractor shall be responsible for preserving the vitality of stockpiled topsoil. Leaching, drying, or heating will be considered to indicate deterioration of topsoil and the Engineer will evaluate the acceptability of stockpiled topsoil material on the basis of these or other indications. Where evaluation indicates that topsoil no longer meets the requirements of subsection 406.02, the topsoil material shall be replaced at the Contractor's expense.

Where specified or directed, the Contractor shall scarify the surface of the underlying course before the topsoil is placed to improve bonding. Scarifying shall be accomplished in such a manner that depressions and ridges so formed shall be parallel to the contours and no deeper than ...... [3 inches suggested] total relief.

Topsoil in an unworkable condition due to excessive moisture, frost, or other conditions shall not be placed until it is suitable for spreading. Topsoil shall be placed on the designated areas and spread to the specified thickness above the tops of any ridges formed by scarification. After the topsoil is spread, all large stiff clods, rocks, roots, or other foreign matter shall be removed from the surface.

406.06 Protection and Maintenance. The Contractor shall be required, within the limits of his contract, to maintain and protect the vegetative layer in good condition and in a manner satisfactory to the Engineer from the time he first starts work until all work has been completed and accepted. Maintenance by the Contractor shall include immediate repairs of any defects, regardless of cause, that may occur. This work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the course continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced for the full depth of the course by the Contractor at his own expense.

406.07 Method of Measurement. Vegetative courses will be measured by the cubic yard in accordance with 109 MEASUREMENT AND PAYMENT. Topsoil thickness shall be as measured above the tops of scarification ridges. When specified (Note) as pay item, water added to the materials will be measured by the 1,000 gallons by means of calibrated tanks or distributors or by means of accurate water meters.

406.08 Basis of Payment. The accepted quantities of Vegetative Layer of the types specified will be paid for at the contract prices for loam course and topsoil course and per 1,000 gallons for water complete in place as follows:

Pay Item	Pay Unit
Loam Course	Cubic yard
Topsoil Course	Cubic yard
Water for Vegetative Course	M.G. or Incidental to loam or topsoil

* * *

610 TURF ESTABLISHMENT

610.01 Description. This work shall consist of soil preparation, seeding, fertilizing, liming if required, and mulching on all areas designated for turf establishment as shown on the plans or where directed by the Engineer.

610.02 Materials. Materials shall meet the requirements specified in the following subsections of 700 MATERIALS DETAILS:

Agricultural Limestone	711.02
Fertilizer	711.03
Seed	711.04
Mulch	711.05
Emulsified Asphalt	702.04

Note: Where its costliness is considered critical, topsoil may need to be measured from the half-height of scarification ridges in order to reduce cost. This detail is typical of the many dilemmas requiring resolution in preparing specifications.

610.03 Scheduling and Seasons. The Contractor shall establish turf as soon as he has satisfactorily completed a unit or portion of the project for partial acceptance as provided under 108 PROSECUTION AND PROGRESS or indicated (Note) on the plans. Discrete units may be the cover system over an individual waste cell; or the portion may be an arbitrarily delineated area which can be protected from further traffic and other disturbance.

The normal seasonal dates for seeding shall be:

Spring seeding ..... [Established locally]
Fall seeding ..... [Established locally]

However, the work may be performed at any season of the year when a mulch is used unless otherwise specified. The Contractor shall notify the Engineer at least 48 hours in advance of the time he intends to begin sowing seed and shall not proceed with such work until permission to do so has been obtained.

When delays in operations carry the work beyond the normal seasonal dates, or when conditions of high winds, excessive moisture, or ice are such that satisfactory results are not likely to be obtained for any stage of the work, the Engineer will stop the work. The work shall be resumed with the Engineer's approval when the desired results are likely to be obtained or when approved corrective measures and procedures are adopted.

610.04 Soil Preparation. All areas to be seeded shall be cultivated to provide a reasonably firm, but friable seedbed. Depth of cultivation shall be as shown on the plans unless otherwise directed by the Engineer. On slopes steeper than 3 horizontal on 1 vertical, depth of cultivation may be reduced as directed. All areas to be seeded shall meet the specified finish grades, be free of any weed or plant growth, stones of ..... [2 inches suggested] in diameter or larger, or other debris. Limestone, if required, shall be applied uniformly either prior to or during soil preparation, and shall be incorporated into the soil surface to the depth shown on the plans. The application of limestone after soil preparation has been completed shall be only on approval of the Engineer. All mechanical equipment for soil preparation shall be as approved and shall pass parallel to the contours unless otherwise approved.

610.05 Testing, Mixing, and Inoculating Seeds. Provisional acceptance of the seeds must be obtained before the seeds are mixed. Each lot of seed shall be subject to sampling and testing before mixing. Sowing seed shall not be delayed pending reports of these tests. Sampling and testing shall be accomplished by an approved testing laboratory at no additional expense to the Owner. Seeds of the kinds specified shall be mixed on the job in the formula specified unless otherwise approved. Seed mixed prior to delivery may be approved on the basis of a certification by the vendor stating the minimum percentage of germination and purity of each kind of seed and the quantity of each kind of seed in the mixture. All seed of leguminous plants shall be inoculated with approved cultures prior to mixing or sowing unless otherwise specified or approved or unless accompanied by a certificate of preinoculation. When seed is to be sown dry and is to be inoculated, the culture shall be applied as directed by the manufacturer and the seed allowed to dry sufficiently to be in the proper condition for mixing or sowing. Seed must be sown within 30 hours after this treatment. Where seed is to be distributed hydraulically, the proper proportion of inoculant may be added to the water and seed mixture, together with any limestone or fertilizer specified, providing the alkalinity of the solution does not exceed 8 pH.

610.06 Application Methods. Seed, fertilizer, limestone, and mulch material may be placed by the following methods:

(a) Hydraulic method. The seed and fertilizer, or the seed, fertilizer, and mulch shall be mixed in the specified amount of water to produce a slurry and then uniformly applied under pressure at the rates and on the areas indicated on the plans. Wood cellulose mulch incorporated as an integral part of the slurry mix shall be added after the seed and fertilizer, and ground limestone if required, have been

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Note: Section 108 PROSECUTION AND PROGRESS is not included in this appendix.

thoroughly mixed. Mixtures shall be constantly agitated from the time they are mixed until they are applied to the seedbed. Such mixtures shall be applied within ..... [8 hours suggested] from the time of mixing. Any area inadequately covered shall be retreated as directed by the Engineer.

When seed, fertilizer, and mulch are applied hydraulically, compaction or rolling will not be required.

(b) Dry method. Drills, cultipackers, fertilizer spreaders, or other approved mechanical seeding equipment may be used to apply seed and fertilizer in dry form.

Fertilizer in dry form, and ground limestone if required, shall be spread separately at the rates indicated on the plans and incorporated in one operation to the required depth on those areas indicated on the plans. Seeded areas shall be compacted within ..... [1 day suggested] after seeding has been completed.

Hand-operated seeding devices may be used when seed, fertilizer, and ground limestone are applied in dry form. Generally, hand-operated seeders shall be used only on areas which are inaccessible to mechanical seeders.

610.07 Application of Mulch. Straw, hay, or other mulch, when specified, shall be spread uniformly over seeded areas at the rate of ..... [1.5 tons/acre suggested]. The mulch may be anchored with the mulch tiller, asphalt emulsion, twine, netting, or other approved tiedown or adhesive materials. When asphalt emulsion is used as a tiedown or adhesive, Type SS-1 or approved equal shall be applied either simultaneously with the straw or hay or in a separate operation.

When immediate protection of newly graded slopes is necessary at other than the normal seeding season, hay or straw mulch shall be applied before the seeding with actual seeding completed later during the specified seeding season.

610.08 Grub Proofing. Grub proofing when specified shall be performed on those areas and with materials and rates of application thereof as shown on the plans.

610.09 Liability. Final acceptance of the seed may be subject to the results of official sampling and testing. The weight of seed sown is based on its labeled purity and germination. Tolerances provided by the testing laboratory and approved by the Engineer for the various seed species shall be used in the determination of whether seed conforms to the labeled purity and germination statements and meets the minimum specified. When, after the application of the appropriate tolerances, the purity and germination of any kind of seed except cereal grain and legumes are shown by the tests to be less than that shown on the label but the germination meets the minimum specified with the appropriate tolerance applied and the specified weight of pure live seed has not been sown, the deficiency shall be sown.

When the germination of any kind of seed except cereal grains and legumes is shown by the tests to be less than the minimum specified, after the appropriate tolerances have been applied, it will be considered a total deficiency. Such deficiency shall require complete reseeding of the kind of seed which was deficient.

Reseeding together with necessary grading and trimming shall be done at the expense of the Contractor by spreading the seed by an approved method and during an approved season.

When, in the judgment of the Engineer, at any time prior to the acceptance of the contract any area which has been seeded fails for any reason to produce a satisfactory growth of grass, the Contractor shall reseed and refertilize such areas in the same manner as specified in the contract and, if deemed necessary by the Engineer, also mulch such areas at the rate specified in the contract.

610.10 Care During Construction. The Contractor shall care for the seeded and mulched areas until final acceptance of the project. Such care shall consist of providing protection against traffic by approved warning signs or barricades and repairing areas damaged following the seeding or mulching operations by wind, water, fire, or other causes. Such damaged areas shall be repaired to reestablish the condition and grade of the area prior to seeding and shall then be refertilized, reseeded, and remulched as specified herein. The Contractor shall keep seeded areas mowed until acceptance of the contract by cutting to a height of 3 inches when growth reaches 6 inches or when the growth tends to smother seedlings or as directed.

610.11 Method of Measurement. Measurement shall be based upon the number of acres, measured to the nearest 0.01 acre, of ground surface actually covered by seed, limestone if required, fertilizer, and mulch of the type specified, completed and accepted.

610.12 Basis of Payment. The accepted quantities of Turf Establishment will be paid for at the contract unit price, which payment shall be full compensation for furnishing and placing all materials, labor, tools, and incidentals necessary thereto except Topsoil Course which will be paid for separately under section 406.

Payment will be made under:

Pay Item	Pay Unit
Turf Establishment, Hydraulic method without mulch	Acre
Turf Establishment, Hydraulic method with mulch	Acre
Turf Establishment, Dry method without mulch	Acre
Turf Establishment, Dry method with mulch	Acre

* * *

702.04 Emulsified Asphalt. Emulsified asphalt shall conform to the requirements of AASHTO M 140 or M 208 or comparable standard.

* * *

703.01 Fine Aggregate for Concrete. Fine aggregate for concrete shall conform to the requirements of AASHTO M 6.

* * *

703.19 Permeable Material. Permeable material for drainage layers or for use in backfilling trenches, under, around, and over underdrains and for other subdrainage purposes shall consist of hard, durable, clean sand, gravel, or crushed stone, and shall be free from organic material, clay balls, or other deleterious substances.

* * *

704.01 Topsoil. Topsoil to be furnished by the Contractor shall consist of loose, friable, sandy loam free of admixture of subsoil, refuse, stumps, roots, rocks, brush, weeds, or other material which would be detrimental to the proper development of vegetative growth. The term used herein shall mean that portion of the soil profile defined technically as the "A" horizon by the Soil Science Society of America. The minimum and maximum pH value shall be ..... [6 and 7 suggested]. Topsoil shall be tested in conformance with the standards of the Association of Official Agricultural Chemists.

Topsoil shall contain a minimum of ..... [5 percent suggested] and a maximum of ..... [15 percent suggested] organic matter. Topsoil shall have a grading analysis as follows:

Sieve Designation	Weight Percent Passing
1 inch	100
1/4 inch	97-100
No. 10	80-100

Particle Sizes	
Sand	#200 sieve to #10 sieve
Silt	0.002 mm to #200 sieve
Clay	0.002 mm or less

	Minimum Percent	Maximum Percent
Sand	20	75
Silt	10	60
Clay	5	30

Topsoil shall not contain stones 2 inches and over in diameter.

Prior to stripping at the source, topsoil shall have demonstrated by the occurrence upon it of healthy crops, grass, or other plant growth, that it is of good quality and reasonably free draining. All testing shall be at the expense of the Contractor. The Contractor will be reimbursed for materials provided to improve the pH, organic matter, or other qualities of the topsoil from the levels required when such improvements are ordered by the Engineer.

* * *

704.05 Clay for Barrier. Clay to be furnished by the Contractor shall consist of clay soil free of refuse, vegetation, and rocks. Clay shall have a grading analysis as obtained according to test methods in ASTM D422 and as defined in the Unified Soil Classification system.

Sieve Designation	Weight Percent Passing
1 inch	100
1/4 inch	95-100
No. 10	80-100

	Minimum Percent	Maximum Percent
Sand	0	20
Silt	10	40
Clay	40	70

Where the source material is clay shale or very stiff clay, D422 testing shall be modified to being conducted on undried, slaked material without blenderization. (Note)

Clay material shall have the following physical characteristics:

(a) Dry enough to spread without reworking.

(b) No reactive components such as fine-grained iron sulfide or carbon which is or may become unstable.

(c) Liquid limit in the range ..... [25-45 suggested] and plasticity index in the range ..... [10-25 suggested].

(d) Nondispersive and not susceptible to piping as evident from results of pinhole test or on basis of past service of the clay material for similar purposes.

* * *

Note: The test requirements may need to be varied from this procedure to simulate long-term effects on the clay soil and its ultimate grain sizes. Testing which includes oven drying will be unrepresentative of the conditions in place and should be avoided.

711.02 Agricultural Limestone. Agricultural limestone shall be ground limestone containing not less than ..... [88 percent suggested] calcium and magnesium carbonates. Limestone shall conform to the standards of the Association of Official Agricultural Chemists and shall comply with all existing State and Federal regulations. Rates of application shall be shown on the plans.

Limestone shall meet the following sieve analysis: at least 40 percent passing the No. 100 sieve and at least 95 percent passing the No. 8 sieve.

711.03 Fertilizer. Fertilizer shall be a standard commercial grade and shall conform to all State and Federal regulations and to the standards of the Association of Official Agricultural Chemists. Commercial fertilizer shall provide the minimum percentage of available nutrients as specified. The Contractor shall furnish an affidavit from the vendor or a testing laboratory as to the available nutrients contained therein.

Fertilizer shall be furnished in bulk or in new, clean, sealed and properly labeled bags. Fertilizer failing to meet the specified analysis may be used as determined by the Engineer providing sufficient materials are applied to comply with the nutrient requirements indicated on the plans without additional cost to the Owner.

A liquid form of fertilizer containing the minimum percentage of available nutrients may be used when approved by the Engineer.

711.04 Seed. The seed shall be furnished separately or in mixtures according to the plans in standard sealed containers, labeled and delivered to the job prior to use for sampling and testing by the Engineer. A certifying statement from the vendor shall be furnished by the Contractor in duplicate verifying seed test and results within 6 months of date of delivery. Seed and labels shall conform to all current State and Federal regulations and will be subject to the testing provisions of the Association of Official Seed Analysts.

Types of seed or seed mixtures shall be as shown on the plans, including the percentage of purity, germination, [Owner may prefer to require "pure live seed"] and weed seed content.

[The use of a form affidavit on the official stationery of the supplier showing all pertinent data for each lot of seed shall be at the discretion of the Owner.] Legume seed when specified in the mixture shall be inoculated with approved cultures in accordance with instructions of the vendor.

711.05 Mulch.

(a) Wood chips. Wood chips shall be obtained from disease-free green hardwood, shall be 1/8 inch nominal thickness, with 50 percent having an area not less than one square inch, nor more than 6 square inches. All wood chip mulch shall be free from leaves, twigs, shavings, bark, or materials injurious to plant growth.

(b) Straw. Straw for mulching shall be from oats, wheat, rye, or other approved grain crops which are free from noxious weeds, mold, or other objectionable material. Straw mulch shall be in an air-dry condition and suitable for placing with mulch blower equipment.

(c) Hay. Hay shall be of approved herbaceous mowings, free from noxious weeds, mold, or other objectionable material. Hay shall be in an air-dry condition and suitable for placing with mulch blower equipment. (Note)

* * *

Note: Specifications may also be needed for sawdust, cellulose fiber, peat moss, peat humus, or rotted manure.

SPECIFICATIONS FOR COVER DESIGN II

The following selected guide specifications might be suitable for contracting for construction of Design II identified as S/F/C/L-1 under EXAMPLE DESIGNS (See page 38). Section numbering below is conformable to the organization of technical provisions in Table 12 on page 36.

204 BACKFILL AND EMBANKMENT*

* * *

301 CLAY BARRIER

(Same as previous 301 CLAY BARRIER* except a cross reference is needed to the restrictions under subsection 404.04 on placement of the bottom lift.)

* * *

403 FILTER LAYER

(Same as previous 403 FILTER LAYER* except material requirements are in subsection 703.21 Fine Aggregate for Underdrain.)

404 FILTER FABRIC (IN PLACE)

404.01 Description. This work shall consist of furnishing and placing a filter fabric on a prepared surface in accordance with these specifications, in reasonably close conformity with the lines, grades, and typical cross sections shown on the plans.

404.02 Materials. Requirements for filter fabric shall be according to subsection 710.11. A file shall be maintained by the Contractor for each shipment, roll, or other convenient, identifiable lot showing the dates received, transferred, and stockpiled along with certification and test documentation. This file will form a basis for evaluating the acceptability of the material at any time up to covering in place. Long storage and excessive exposure will be unacceptable and shall necessitate replacement of affected materials.

404.03 Preparation of Fabric Foundation. The sand course serving as foundation shall be cleaned and shall be cleared of sharp objects which might damage the fabric during installation. Any condition of surface looseness such as from drying shall necessitate sprinkling and rolling or tamping to restore firmness.

404.04 Placing. The filter fabric shall be unrolled directly on the foundation, overlapping all fabric sections by ..... [3 feet suggested]. Unless approved otherwise by the Engineer in advance, the overlap shall be stapled, bonded, or sewed or otherwise fastened. On ground sloping more than ..... [5 percent suggested], the Engineer may require that fabric be unrolled across contours.

Should the fabric be damaged during any step of the installation, the torn or punctured section shall be repaired by placing a piece of fabric large enough to cover the damaged area and to provide overlap directly on top of and extending 3 feet beyond the damaged area.

Vehicles and equipment such as loaders and dozers shall be prevented from operating directly on the fabric. These units may operate on the first lift of the overlying course provided that lift is at least ..... [6 inches suggested] in thickness and free of stones and other hard objects greater than ..... [1/8 inch suggested] in largest diameter and provided the units have wide tracks or extra wheels exerting ground pressures sufficiently low as to avoid rutting or cleating to more than ..... [1/5 suggested] the thickness of the lift. Dozer blades, etc. shall not make direct contact with the fabric; however, if tears, punctures, or damaging abrasions occur in the fabric during the spreading operation, the material above shall be cleared from the fabric and the damaged area repaired as previously described.

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* See under Design I

Overlying soil material shall be spread in the direction of fabric overlap, i.e. such that soil does not move beneath the top half of the overlap. Large fabric wrinkles which may develop during spreading operations shall be folded and flattened in the direction of the spreading. Occasionally, large folds may tend to reduce the fabric overlap width. Special care shall be given to maintain proper overlap and fabric continuity.

404.05 Construction Joints and Surfaces. The work shall be scheduled and temporary or permanent covering shall be provided to preserve the original properties of the filter fabric. Overlap interfaces shall be free of soil and debris. Seaming accomplished in the field shall be according to recommendations of the manufacturer of the fabric. Such recommendations shall be provided to the Engineer for review at least 2 weeks prior to the start of seaming.

404.06 Protection and Maintenance. The Contractor shall maintain the filter fabric in good condition and in a manner satisfactory to the Engineer from the start of work until all work has been completed and accepted. Maintenance shall include immediate repair of any defects regardless of the cause. This work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the fabric continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced by the Contractor at his own expense.

404.07 Method of Measurement. Filter fabric will be measured in place by the square yard of coverage ordered placed. Overlaps shall not count extra.

404.08 Basis of Payment. The accepted quantities of Filter Fabric (In Place) of the type specified will be paid at the contract price and will include all material, equipment, tools, labor, and incidentals necessary to complete this item of work.

Payment will be made under:

Pay Item	Pay Unit
Filter Fabric (In Place)	Square yard

* * *

406 VEGETATIVE LAYER*

* * *

610 TURF ESTABLISHMENT*

* * *

702.04 Emulsified Asphalt.*

* * *

703.19 Permeable Material.*

* * *

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* See under Design I

703.21 Fine Aggregate for Underdrain. The fine aggregate shall meet the requirements of AASHTO M 6. [Alternative gradation specifications may be supplied by the Owner.]

* * *

704.01 Topsoil.*

* * *

704.05 Clay for Barrier.*

* * *

710.11 Filter Fabric. The filter fabric shall be composed of strong rotproof polymeric fibers formed into a fabric of either the woven or nonwoven type. Both type fabrics shall be free of any treatment or coating which might significantly alter physical properties. Fabric shall meet the requirements of Table 710.11A or 710.11B. (Note)

A competent laboratory shall be maintained or retained by the producer of the fabric at the point of manufacture to ensure quality control. Intermediate processors such as those seaming rolled sheeting into larger pieces shall be included in this requirement to the extent that their processing and handling affect the fabric.

During all periods of shipment and storage, the fabric shall be protected in a heavy-duty covering from direct sunlight, ultraviolet rays, temperatures greater than 140°F., mud, dirt, dust, and debris.

The Contractor shall furnish certified test reports with each shipment of material attesting that the fabric meets the requirements of this specification. A sample of 5 square yards of fabric from each shipment shall be furnished the Owner for verification testing. Samples shall be provided at no cost to the Owner.

* * *

711.02 Agricultural Limestone.*

* * *

711.03 Fertilizer.*

* * *

711.04 Seed.*

* * *

711.05 Mulch.*

* * *

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* See under Design I

Note: Tables for example only; methods and requirements are not confirmed.

TABLE 710.11A. REQUIREMENTS FOR WOVEN FILTER FABRIC

Test	Method	Requirements
Tensile Strength (unaged cloth)*	ASTM D 1682 Grab Test Method 1 square inch jaws; rate of 12 inches/minute.	Minimum 200 pounds in any principal direction. Apparent elongation at failure between 10 and 35 percent.
Bursting Strength (unaged cloth)*	ASTM D 751 Diaphragm Bursting Tester	Minimum 500 psi
Puncture Strength (unaged cloth)*	ASTM D 751 Tension Testing Machine with Ring Clamp; steel ball replaced with a 5/16 inch diameter solid steel cylinder centered within the ring clamp.	Minimum 120 pounds
Abrasion Resistance	ASTM D 1682 as above, after abraded as in ASTM D 1175 Rotary Platform, Double Head Method; rubber-base abrasive wheels equal to CS-17 "Calibrase"; 1 kilogram load per wheel; 1,000 revolutions.	Minimum 55 pounds in any principal direction
Seam Breaking Strength	ASTM D 1683, 1 square inch jaws; rate of 12 inches/minute.	Minimum 180 pounds
Permeability	ASTM D 4491 Permittivity	Minimum 3.3 x 10^{-2} cm/sec. Maximum 3.8 x 10^{-2} cm/sec.

*Unaged is the condition as received from the manufacturer or distributor.

TABLE 710.11B. REQUIREMENTS FOR NONWOVEN FILTER FABRIC

Test	Method	Requirement
Grab Strength*	ASTM D 1682**	Minimum 90 pounds
Grab Elongation*	ASTM D 1682**	Minimum 50 percent
Permeability*	ASTM D 4491	Minimum 2 x 10^{-2} cm/sec. Maximum 3 x 10^{-2} cm/sec.
Fabric Toughness (Grab Strength x Grab Elongation)		Minimum 8000 (lb-percent)

*Tests run on wet samples soaked 24 hours at ambient room temperature.
**Tensile strength determined by the method stated in Table 710.11A.

SPECIFICATIONS FOR COVER DESIGN III

The following selected guide specifications might be suitable for contracting for construction of Design III identified as M/S/G-1 under EXAMPLE DESIGNS (See page 38). Section number below is conformable to the organization of technical provisions in Table 12 on page 36. A separate filter blanket is included with STONE PROTECTION but may be omitted when the sand-gravel interface is expected to remain stable.

204 BACKFILL AND EMBANKMENT*

* * *

303 SYNTHETIC MEMBRANE BARRIER

303.01 Description. This work shall consist of furnishing and placing a synthetic membrane barrier on a prepared surface in accordance with these specifications, in reasonably close conformity with the lines, grades, and typical cross sections shown on the plans or established by the Engineer.

303.02 Materials. Requirements for membrane material shall be according to subsection 710.10. Membrane thickness shall be at least ..... [40 mils suggested]. A file shall be maintained by the Contractor for each shipment, roll, or other convenient, identifiable lot, showing the dates received, transferred, and stockpiled along with certification and test documentation. This file will form a basis for evaluating the acceptability of the material at any time up to covering in place. Long storage and excessive exposure will be unacceptable and shall necessitate replacement of affected materials.

303.03 Preparation of Membrane Foundation. The sand course or other soil serving as foundation for the membrane shall be cleaned and shall be cleared of sharp objects which might damage the membrane during installation. Any condition of surface looseness such as from drying shall necessitate sprinkling and rolling or tamping to restore firmness.

303.04 Placing. The synthetic membrane shall be unrolled or unfolded directly on top of the foundation, overlapping all membrane sections sufficiently for seaming and allowance for relaxation. Seaming shall be according to the methods of field seaming prescribed by the manufacturer of the membrane sheeting. Such methods shall be conformable to the desired results, including impermeability and durability.

On ground sloping more than ..... [5 percent suggested], the fabric shall be unrolled across contours. An anchor trench shall be provided at the top.

Should the membrane be damaged during any step of the installation, the torn or punctured section shall be repaired by placing a piece of membrane large enough to cover the damaged area and to provide overlap directly on top of and extending 1 foot beyond the damaged area. The manufacturer's recommendations shall be followed for bonding the patch to the sheet and in other repairs of similar consequence.

Vehicles and equipment such as loaders and dozers shall be prevented from operating directly on the membrane. These units may operate on the first lift of the overlying course provided that lift is at least ..... [6 inches suggested] in thickness and free of stones and other hard objects greater than ..... [1/8 inch suggested] in largest diameter and provided the units have wide tracks or extra wheels exerting ground pressures sufficiently low as to avoid rutting or cleating to more than ..... [1/5 suggested] the thickness of the lift. Dozer blades, etc. shall not make direct contact with the membrane;

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* See under Design I

however, if tears, punctures, or damaging abrasions occur in the membrane during the spreading operation, the material above shall be cleared from the membrane and the damaged area repaired as specified above.

303.05 [Reserved] (Note)

303.06 Construction Joints and Surfaces. The work shall be scheduled and temporary or permanent covering shall be provided to preserve the original properties of the membrane material. Overlap interfaces shall be free of soil and debris. Seaming accomplished in the field shall be according to recommendations of the manufacturer of the membrane. Such recommendations shall be provided to the Engineer for review at least two weeks prior to the start of seaming.

303.07 Protection and Maintenance. The Contractor shall maintain the membrane in good condition and in a manner satisfactory to the Engineer from the time he first starts work until all work has been completed and accepted. Maintenance shall include immediate repair of any defects, regardless of the cause. This work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the membrane continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced by the Contractor at his own expense.

303.08 Method of Measurement. Synthetic membrane will be measured in place by the square yard of coverage ordered placed. Overlaps shall not count extra.

303.09 Basis of Payment. The accepted quantities of Synthetic Membrane Barrier of the type specified will be paid for at the contract price and will include all material, equipment, tools, labor, and incidentals necessary to complete this item of work.

Payment will be made under:

Pay Item	Pay Unit
Synthetic Membrane Barrier	Square yard

* * *

402 STONE PROTECTION

402.01 Description. This work shall consist of placing protective stone covering and filter blanket as shown on the plans or directed by the Engineer. It further includes the preparation of the foundations, the construction of the toe ditch, and the disposal of excess fill and excavated materials.

402.02 Materials. All materials shall be gravel or crushed stone meeting the requirements of the following specifications:

Protection Stone	705.01
Filter Stone	705.02

except where broken concrete is permitted as a substitute for stone by the Engineer.

402.03 Preparation of Foundations. The ground surface upon which the stone and filter blankets are to be placed shall be brought into reasonably close conformity to the correct lines, grades, and density before placement is commenced. On slopes, the stone blanket shall begin in a toe ditch. The toe ditch shall be ..... [2 feet suggested] deep and the side next to the fill shall have the same slope. After the stone blanket is placed, the toe ditch shall be backfilled.

Note: A subsection on cold-weather construction and restrictions may be needed in regions subject to cold weather.

402.04 Stone Blanket. Stone blanket shall be placed to the thickness and limits shown and to a thickness tolerance of plus or minus ..... [1/2 inch suggested]. The stone shall be handled into place to form a neat, uniform, reasonably compact layer in which the smaller stones are not segregated but remain evenly distributed within the blanket.

402.05 Filter Blanket. Filter blanket material shall be uniformly placed to the thickness and limits shown and to a thickness tolerance of plus or minus ..... [1/2 inch suggested]. It shall be compacted to the extent necessary to hold it in place while the stone blanket is placed upon it. The filter blanket shall be placed after the stone blanket is placed in the toe ditch and before the stone blanket is placed upon the slopes.

402.06 Method of Measurement. This work will be measured for payment in cubic yards of accepted material. No separate measurement will be made for excavation and disposal.

402.07 Basis of Payment. This work will be paid for at the contract price complete in place as follows:

Pay Item	Pay Unit
Stone Blanket Protection	Cubic yard
Filter Blanket	Cubic yard

* * *

405 DRAINAGE LAYER

405.01 Description. This work shall consist of furnishing and placing a sand drainage course on a prepared surface in accordance with these specifications, in reasonably close conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans or established by the Engineer.

405.02 Materials. The drainage material shall be homogeneous sand and shall meet the requirements of subsections 703.19 and 703.01. Material will be accepted based on testing of samples representative of loads delivered.

405.03 [Reserved] (Note)

405.04 Placing and Spreading. Sand material for each lift of the drainage course shall be placed and spread in such ways as to avoid material segregation and mixing with or damage to the previous lift or the course foundation. The Contractor shall understand that segregations, or mixtures, or cracks, ruts, offsets, punctures, and other indications of damage to underlying material by equipment or procedures will constitute valid criteria for rejection and will necessitate replacement of rejected elements at the expense of the Contractor.

The thickness of the loose lift shall be such as will meet the required compacted thickness specified in subsection 405.05.

405.05 Compacting. Loose lifts of sand material shall be compacted by equipment and procedures capable of attaining the prescribed density without damage to the lift being compacted or to the underlying material. Compactors that impart a kneading action or penetrate the top surface of the lift shall not be used unless approved by the Engineer. An appropriately sized tire-roller compactor will usually be acceptable.

The required density for compaction shall be ...... [85 percent suggested] of maximum density. The Contractor shall provide the maximum and minimum density parameters for the chosen sand material along with the calculated relative density required by this contract at least two weeks prior to placing sand material in the course. Details of the test methods shall be provided also. A method using a vibratory table is usually preferred for determination of maximum relative density.

Note: Specifications on preparation and checking of condition of membrane immediately below may be needed here for Design III.

The course shall be constructed in lifts not exceeding ...... [6 inches suggested], and lift thicknesses in multiple-lift courses shall be approximately equal. Compaction shall continue until a density not less than the required density has been achieved to the full depth of the lift. Water shall be applied uniformly over the materials during compaction in the amount necessary for proper compaction.

In-place field density shall be determined in accordance with ASTM D1556, D2167, D2937, or D2922. The Contractor is responsible for testing but may use an approved commercial testing laboratory. All costs of sampling and testing shall be borne by the Contractor.

405.06 Construction Joints and Surfaces. At the end of each day's construction a lateral construction joint shall be marked if not clearly evident. Temporary covering may be required to preserve the as-constructed condition intended. Upon resumption of work the joint shall be uncovered and moistened as needed to assure interlock along the joint when the lift is extended.

Course surfaces shall similarly be protected by temporary cover, to be removed completely upon resumption of work with addition of the course above.

405.07 Protection and Maintenance. The Contractor shall be required to maintain and protect the drainage layer in good condition and in a manner satisfactory to the Engineer from the time he first starts work until all work has been completed and accepted. Maintenance by the Contractor shall include immediate repairs of any defects, regardless of the cause. This work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the course continuously intact. Repairs are to be made in a manner to ensure restoration of a uniform surface and durability and integrity of the part repaired. Faulty and damaged work shall be replaced for the full depth of the course by the Contractor at his own expense.

405.08 Method of Measurement. Sand course will be measured by the cubic yard in accordance with 109 MEASUREMENT AND PAYMENT. When specified as pay item, water added to the materials will be measured by the 1,000 gallons by means of calibrated tanks or distributors or by means of accurate water meters.

405.09 Basis of Payment. The accepted quantities of Drainage Layer, of the type specified, will be paid for at the contract price as follows:

Pay Item	Pay Unit
Drainage Layer Course	Cubic yard
Water for Drainage Layer Course	M.G. or incidental to sand

* * *

703.01 Fine Aggregate for Concrete.*

* * *

703.19 Permeable Material.*

* * *

705.01 Protection Stone. In addition to meeting the quality requirements of AASHTO M 80, protection stone material shall be in accordance with AASHTO M 43, No. 357.

705.02 Filter Stone. In addition to meeting the quality requirements of AASHTO M 80, filter blanket material shall conform to the gradation requirements of AASHTO M 43, No. 467.

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* **See under Design I**

710.01 Manufacturer's Instructions. Instructions certified as suitable for the purpose by the manufacturer of the sheeting shall be supplied for placement, seaming, bonding, and other procedures anticipated in completing the barrier. The instructions shall be appropriate for the chosen membrane including its specific thickness or gauge. The instructions shall be provided to the Engineer no less than one week prior to first delivery of membrane material to the job site.

* * *

710.10 Polyvinyl Chloride. Polyvinyl chloride sheeting shall meet the requirements of Table 710.10 and shall be free of treatment or coating which (Note) might significantly alter physical properties. A competent laboratory shall be maintained or retained by the producer of the sheeting at the point of manufacture to ensure quality control. Intermediate processors such as those seaming rolled sheeting into larger pieces shall be included in this requirement to the extent that their processing and handling affect the membrane.

During all periods of shipment and storage, the membrane shall be protected in a heavy-duty covering from direct sunlight, ultraviolet rays, temperatures greater than 140°F., mud, dirt, dust, and debris.

The vendor shall furnish certified test reports with each shipment of material attesting that the cloth meets the requirements of this specification. A sample of 5 square yards shall be furnished the Owner from each shipment for verification testing. Samples shall be at no cost to the Owner.

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SPECIFICATIONS FOR COVER DESIGN IV

The following selected guide specifications might be suitable for contracting for construction of Design IV identified as C/S/B-1 under EXAMPLE DESIGNS (See page 38). Section numbering below is conformable to the organization of technical provisions in Table 12 on page 36.

204 BACKFILL AND EMBANKMENT*

* * *

301 CLAY BARRIER

(Same as previous 301 CLAY BARRIER* except material requirements are relaxed to allow use of till or other native soil).

* * *

304 BLOCK BARRIER

304.01 Description. This work shall consist of constructing a block surface course in accordance with these specifications and in conformity with the lines, grades, thicknesses, and typical sections shown on the plans. The work includes the furnishing of plant, labor, equipment, and materials to place the course. A course of cushion sand shall be required where the underlying course is not suitable for embedding the blocks.

Note: This table is preliminary and subject to change. See the original source SW-870 (32)

* See under Design I

TABLE 710.10. MATERIAL PROPERTIES OF UNSUPPORTED POLYVINYL CHLORIDE (PVC)

Property	Test Method	Gauge (nominal)		
		20	30	45
Thickness	ASTM D1593 Para 8.1.3	±5%	±5%	±5%
Specific Gravity (minimum)	ASTM D792 Method A	1.20	1.20	1.20
Minimum Tensile Properties (each direction)	ASTM D882			
1. Breaking Factor (pounds/inch width)	Method A or B (1 inch wide)	46	69	104
2. Elongation at Break (percent)	Method A or B	300	300	300
3. Modulus (force) at 100% Elongation (pounds/inch width)	Method A or B	18	27	40
Tear Resistance (pounds, minimum)	ASTM D1004	6	8	11
Low Temperature	ASTM D1790	-15°F	-20°F	-20°F
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	±5	±5	±5
Water Extraction	ASTM D1239	-.35% max.	-.35% max.	-.35% max.
Volatile Loss	ASTM D1203 Method A	0.7% max.	0.5% max.	0.4% max.
Resistance to Soil Burial* (percent change maximum in original value)	ASTM D3083 120 day soil burial			
1. Breaking Factor		-5	-5	-5
2. Elongation at Break		-20	-20	-20
3. Modulus at 100% Elongation		±10	±10	±10
Bonded Seam Strength** (factory seam, breaking factor, ppi width)	ASTM D3083	36.8	55.2	83.2
Hydrostatic Resistance (pounds/sq in. minimum)	ASTM D751 Method A	60	82	100

*Test value of "after exposure" sample is based on precut sample dimension. 120-day test is required for initial certification.

**Factory bonded seam strength is the responsibility of the fabricator.

304.02 **Materials.** The concrete block shall comply with the requirements for concrete block for slope paving in subsection 705.04. The block shall have the following nominal dimensions: (Note)

Length ..... [12 inches suggested]
Thickness ..... [4 inches suggested]
Width ..... [8 inches suggested]

The standard dimensions of the block shall be the specified nominal dimension minus 3/8 inch. The maximum permissible variation in dimensions of individual units from standard dimensions shall be not more than 1/8 inch. The size of block used shall be consistent throughout any continuously paved area. All units shall be sound and free from cracks or other defects that would interfere with the proper placing of the blocks or impair the strength, permanence, and appearance of the construction.

Cushion sand shall conform to the requirements set forth in subsection 703.06. Grout, where used, shall consist of one part masonry cement conforming to the requirements of subsection 701.01, and two parts mortar sand, conforming to the requirements of subsection 703.03.

304.03 **Placement.** Blocks shall be laid on a 3-inch bed of cushion sand or material acceptable to the Engineer as equivalent to cushion sand. An underlying course composed of sand free of pebbles and larger pieces will serve as cushion where approved as such by the Engineer and provided such substitution does not result in a thickness deficiency.

Placement shall be in running bond with the long dimension transverse to the slope and all joints tight. Blocks shall be thoroughly rammed in place to provide a uniformly even surface and solid bedding under each block.

Gaps in the block course over irregular topography, at boundaries, and against structures shall be filled with grout to the full depth of the course. Otherwise, joints between blocks shall be grouted only where indicated on the plans.

304.04 **Grouting.** Where grouting is indicated on the plans, the concrete block shall be laid in running bond with the length parallel to the slope and with 1/4-inch joints. Following the laying of blocks, in the area to be grouted, sufficient mortar sand shall be spread over the surface and swept into the joints to fill the latter to ..... [3 inches suggested] from the surface. The block shall be wetted to the satisfaction of the Engineer before any grout is placed. The joints shall be filled with grout from the bottom flush with the top of the block.

After grouting has been completed and the grout has sufficiently hardened, the blocks shall be wetted and covered, and allowed to cure for the first seven days after grouting. Grout shall not be poured during freezing weather.

304.05 **Method of Measurement.** The quantity to be paid under this item shall be the number of square yards computed from the payment lines shown on the plans, or as directed by the Engineer.

304.06 **Basis of Payment.** The unit price bid for this item shall include the costs of furnishing all materials, labor, and equipment necessary to complete the work satisfactorily.

Payment will be made under:

Pay Item	Pay Unit
Concrete Block Paving	Square yard

* * *

Note: A substantial cost savings may come from using brick or other available commercial blocks provided that ground moisture is not detrimental to durability.

405 DRAINAGE LAYER

(Same as previous 403 FILTER LAYER* except sand material described under subsection 703.15 is required in place of sand under subsection 703.01).

* * *

701.01 Portland Cement. Portland cement shall conform to the requirements of the following cited specifications for the type specified or permitted:

Type	Specification
Portland Cement	AASHTO M 85
Blended Hydraulic Cement	AASHTO M 240
Masonry Cement	AASHTO M 150

Unless otherwise permitted by the Engineer, the product of only one mill of any one brand and type of Portland cement shall be used on the project, except for reduction of any excessive air where air-entraining cement is used.

The Contractor shall provide suitable means for storing and protecting the cement against dampness. Cement which, for any reason, has become partially set or which contains lumps of caked cement shall be rejected. Cement salvaged from discarded or used bags shall not be used.

* * *

703.03 Mortar Sand. Mortar sand shall consist of clean, hard, durable, uncoated particles, free from lumps of clay and all deleterious substances.

When dry the mortar sand shall meet the following gradation requirements:

Sieve Designation	Weight Percent Passing
#4	100
#8	95-100
#50	10- 40
#100	0- 15

* * *

703.06 Cushion Sand. Cushion sand shall consist of clean, hard, durable, uncoated particles, free from lumps of clay and all deleterious substances.

When dry, the cushion sand shall meet the following gradation requirements:

Sieve Designation	Weight Percent Passing
1/4 inch	100
No. 50	0-35
No. 100	0-10

The sand may be determined to be unacceptable for cushion sand if it contains more than 10 percent by weight of loam or silt.

* * *

703.15 Aggregate for Masonry Mortar. Aggregate for masonry mortar shall meet the requirements of AASHTO M 45.

* * *

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* See under Design I

703.19 Permeable Material.*

* * *

705.04 Concrete Block for Slope Paving. The shape and dimensions of the units shall be shown in the plans or specifications. The minimum average compressive strength of concrete paving block shall be 2,500 pounds/square inch. This strength shall be determined by load application in a direction parallel to the slope upon which the block is to be placed. The compressive strength of any individual unit shall be not less than 2,000 pounds/square inch. The strength shall be taken directly from unit samples from any lot.

The maximum average absorption of concrete paving block samples representing any lot shall not exceed 8 percent by weight. The absorption of any individual unit shall not exceed 10 percent by weight.

All test procedures shall be in accordance with ASTM C140.

* * *

SPECIFICATIONS FOR COVER DESIGN V

Cover Design V under EXAMPLE DESIGNS (See page 38) reflects current RCRA guidance. No specifications are offered for this design in order to avoid direct application of such specifications without the benefit of thorough and detailed engineering analyses to address the specifics of any new facility.

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* See under Design I

APPENDIX B

RELATED SPECIFICATIONS

The following specifications are taken directly from outside sources without modification to illustrate special method or details. The excerpts are not necessarily directly applicable to cover construction and maintenance. The examples illustrate indirectly the detailed consideration sometimes regarded as necessary in similar construction.

MIXING SOILS

The following excerpt is from a set of specifications for constructing subbase for flexible pavements using soils needing additional mixing during placement. The source is the Department of the Navy. Note that the paragraph numbers do not mesh with those suggested elsewhere in this document (Table 12 on page 36).

> 3.1 PLACING: Clean underlying surface of all foreign substances and inspect for proper compaction and smoothness before placement of subbase course. When the temperature falls below 35°F, protect all areas of completed subbase course against freezing.
>
> 3.1.1 Road Mix Method: Haul materials to area to be paved and spread uniformly from spreader boxes, moving vehicles, or by other approved methods. Coarse material may be placed in a uniform layer on the underlying course followed by spreading a uniform layer of fine material, or materials may be placed in windrows on the underlying course. Place coarse and fine materials in proportions such that, when blended, they shall conform to the requirements specified. Mix windrowed material using blade graders, harrows, disks, or other suitable equipment. Mixing shall not disturb the underlying course. Continue initial mixing until the mixture is uniform throughout its depth adding water as necessary to prevent segregation during mixing operations. Sprinkle additional water, as required, to facilitate satisfactory mixing. Continue mixing until the water is uniformly distributed throughout the mixture. Add fine or coarse material, or both, to the mixture, as required, to secure compaction and density specified. After materials are thoroughly mixed and compacted, the resulting layer shall conform to the indicated thickness.
>
> 3.1.2 Mixed-in-Place Method: Loosen, pulverize, and blade to a uniform depth the existing subgrade material which is suitable for use for the subbase course when blended with the required proportions of other aggregates or binding material. Spread aggregates or binding material, or both, in uniform layers of such depth that when the materials are thoroughly mixed and compacted the resulting layer shall conform to the indicated thickness and cross section. Continue initial mixing until mixture is uniform throughout. Remove portions of any layer in which segregation of material occurs and replace with satisfactory material, or add suitable material and mix with the segregated material.

3.1.3 Windrow Traveling-Plant Method: Blend and deposit haul materials in windrows on the underlying course in such proportions that the specified gradation shall be met. Size of windrow shall not exceed the mixing capacity of the traveling plant. Make adjustments in the amounts of the various materials being blended when so directed. Mixing operation shall produce a satisfactory, uniform, blended material when deposited on underlying course in windrows of uniform cross section. Spread windrowed mixed material to required contour and uniform thickness and to the depth that when compacted, the resulting layer shall conform to the indicated thickness and cross section.

QUALITY CONTROL AND ACCEPTANCE

The Virginia Highway Department developed and uses the following construction specifications for quality of bituminous concrete for pavements. Note that the section numbers do not correlate with those suggested elsewhere in this document (Table 12 on page 36). Substantial differences in scale and cost in cover construction may dictate a much smaller effort and reduced scope in such specifications used there.

Section 212.29: Acceptance - Sampling for determination of gradation and asphalt content will be performed at the plant, and no further sampling will be performed for these properties. However, should visual examination reveal that the material in any batch or load is obviously contaminated, deficient in asphalt content or not thoroughly mixed, that batch or load will be rejected without additional sampling or testing of the lot. In the event it is necessary to determine, quantitatively, the quality of the material in an individual batch or load, one sample (taken from the batch or load) will be tested and the results compared to the "process tolerance for one test" as described hereinbelow. The results obtained in the testing of a specific individual batch or load will apply only to the batch or load in question. Gradation and asphalt content determinations will be performed in the plant laboratory furnished by the Contractor; however, the Department reserves the right to discontinue the use of the plant laboratory for acceptance testing in the event of mechanical malfunctions in the laboratory equipment and in cases of emergency involving plant inspection personnel. In the event of such malfunctions or emergencies, acceptance testing will be performed at the District or Central Office laboratory until the malfunction or emergency has been satisfactorily corrected or resolved.

Acceptance for gradation and asphalt content will be based upon a mean of the results of four tests performed on samples taken in a stratified random manner from each 2,000 ton lot (4,000-ton lot when the contract item is in excess of 50,000 tons). A lot will be considered to be acceptable for gradation and asphalt content if the mean of the results obtained from the four tests fall within the following process tolerances allowed for deviation from the job-mix formula:

Sieve	Process Tolerance (percent passing)
Top size	±0.0
1 1/2"	5.5
3/4"	5.5
1/2"	5.5
3/8"	5.5
#4	4.5
#8	4.5
#30	4.5
#50	3.0
#200	1.5
Asphalt content*	0.5

*Asphalt content will be measured as extractable asphalt.

In the event asphalt input is monitored by automated recordation, the above process tolerance for asphalt will not apply. Variability control for asphalt content will be evaluated based upon extractable asphalt. At any time the asphalt content, as evidenced by automated recordation, deviates more than ±0.2 percent from that shown in the job-mix formula, the production shall be halted and corrective action taken to bring the asphalt content to within this tolerance.

The temperature of the mixture at the plant shall not vary more than ±20°F from the approved job-mix temperature. The temperature of the mixture at the time of placement in the road shall not be more than 30°F below the approved job-mix temperature. Loads which do not conform to these temperature tolerances will be rejected.

In the event that the job requires less than 2,000 tons of material; or that the amount of material necessary to complete the job is less than 2,000 tons (4,000 tons for contract items in excess of 50,000 tons); or that the job-mix formula is modified within a lot, the mean results of samples taken will be compared to a new process tolerance, computed as follows:

Process tolerance for one test = process tolerance for mean of four tests/0.5

Process tolerance for mean of two tests = process tolerance for mean of four tests/0.7

Process tolerance for mean of three tests = process tolerance for mean of four tests/0.9

Individual test results and lot averages obtained from acceptance testing will be plotted on control charts as the information is obtained. Standard deviations, when computed, will be made available to the Contractor. However, the Inspector will in no way attempt to interpret test results, lot averages or standard deviations for the Contractor in terms of needful plant or process adjustments.

Section 212.30: Adjustment System - An adjustment of the unit bid (Note) price will not be made for the value of one test result or the mean value of two or three test results, unless circumstances as stated in Section 212.29 require that the lot size be less than 2,000 tons (4,000 tons for contract items in excess to 50,000 tons). Should

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Note: Substandard materials or construction may be determined to be unacceptable at waste disposal facilities, regardless of penalties, as a matter of policy.

the value of one test result or the mean value of two or more test results, as required by Section 212.29 fall outside the allowable process tolerance, an adjustment will be applied to the unit bid price as follows:

Sieve	Adjustment points for each 1 percent that the gradation is out of process tolerance
2"	1
1 1/2"	1
1"	1
3/4"	1
1/2"	1
3/8"	1
#4	1
#8	1
#30	2
#50	2
#200	3

A one-point adjustment will be applied for each 0.1 percent that the material is out of the process tolerance for asphalt content. In the event the total adjustment for a lot is greater than 25 points, the failing material shall be removed from the road. In the event the total adjustment is 25 points or less and the Contractor does not elect to remove and replace the material, the unit price paid for the material will be reduced 1 percent of the unit price bid for each adjustment point. The adjustment will be applied to the tonnage represented by the sample or samples.

The Contractor shall control the variability of his product in order to furnish the project with a uniform mix. When the contract item is greater than 4,000 tons and an adjustment is necessary as indicated in the following table, it shall be for the entire quantity of that type material on the project based upon its variability as measured by the standard deviation.

Sieve Size and Asphalt Content	Standard Deviation		
	1 Adjustment Point	2 Adjustment Points	3 Adjustment Points
1 1/2"	4.6-5.5	5.6-6.5	6.6-7.5
3/4"	4.6-5.5	5.6-6.5	6.6-7.5
1/2"	4.6-5.5	5.6-6.5	6.6-7.5
3/8"	4.6-5.5	5.6-6.5	6.6-7.5
#4	4.6-5.5	5.6-6.5	6.6-7.5
#8	4.1-5.0	5.1-6.0	6.1-7.0
#30	4.1-5.0	5.1-6.0	6.1-7.0
#50	3.1-4.0	4.1-5.0	5.1-6.0
#200	2.1-3.0	3.1-4.0	4.1-5.0
Asphalt content	0.33-0.42	0.43-0.52	0.53-0.62

The unit bid price shall be reduced by 0.5 percent for each adjustment point applied.

The disposition of material having standard deviations larger than those shown in the table, shall be determined by the Engineer.

PROOF ROLLING

The following specifications detail the procedures of proof rolling sometimes required by the New York Department of Transportation. The major differences in firmness of foundations for cover systems as compared to those for highway pavement systems should be considered carefully. Differences will affect equipment selection as well as procedures. Note that the paragraph and table numbers do not mesh with those suggested elsewhere in this document (Table 12 on page 36).

203-3.13 Proof Rolling in Embankment Sections. Immediately prior to final trimming of the subgrade surface and placement of sub-base materials in embankment sections, all areas of the subgrade surface within roadway limits shall be proof rolled according to the requirements of this article.

A. Purpose. The purpose of proof rolling embankments is to ascertain the uniformity of compaction beneath the subgrade surface, to locate deficiencies requiring correction, and to establish that corrective work has been effective, all prior to placement of the subbase.

B. Equipment. The proof roller shall consist of a chariot type rigid steel frame with a box body suitable for ballast loading up to fifty (50) tons gross weight, and mounted on four (4) pneumatic tired wheels acting in a single line across the width of the roller on its transverse load center line. The wheels shall be equipped with 18.00 x 24, or 18.00 x 25, 24 ply tires, and shall be suspended on articulated axles such that all wheels carry approximately equal loads when operating over uneven surfaces.

C. Determination of Roller Stress. Initially the gross ballasted weight and tire inflation pressure of the proof roller shall be adjusted to the highest stress level shown in Figure 203-4 based on:

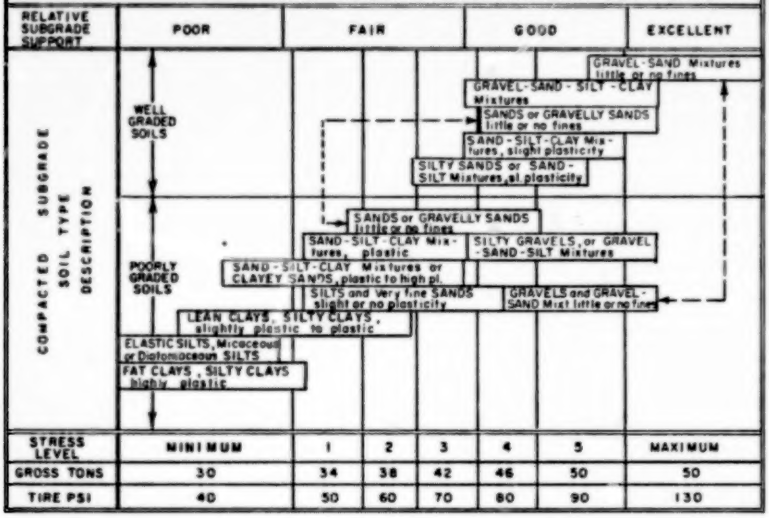
1. The Engineer's general description of the subgrade soils.
2. The Engineer's estimation of the relative subgrade support within the subgrade soil description range.

Where the embankment thickness provides less than 3 feet of cover over the embankment foundation, the initial stress level shall be based upon the embankment foundation soil description whenever a lower initial stress level will result.

The roller shall be operated briefly to establish the acceptability of the initial stress level. Proof rolling of the embankment shall be performed at the *next lower* stress level whenever operation of the roller at a higher stress level is accompanied by consistent *lateral* displacement of soil out of the wheel paths.

D. Procedure. After an acceptable stress level is established, two complete passes of the roller shall be applied over all elements of the area to be proof rolled. Any deficiencies disclosed during the proof rolling operation shall be corrected. Subsidence depressions shall be filled with material similar to the subgrade soil and then compacted in a normal manner. After compaction, these areas shall be proof rolled again. Corrective work shall be judged complete and accepted by the Engineer when all elements of the subgrade surface over a given embankment show a satisfactory uniform response to the proof roller.

Figure 203-4 GUIDE FOR SELECTING THE INITIAL STRESS LEVEL FOR PROOF ROLLING EMBANKMENT SECTIONS


RELATIVE SUBGRADE SUPPORT
POOR
FAIR
GOOD
EXCELLENT
COMPACTED SUBGRADE SOIL TYPE DESCRIPTION
WELL GRADED SOILS
POORLY GRADED SOILS
GRAVEL-SAND Mixtures little or no fines
GRAVEL-SAND-SILT-CLAY Mixtures
SANDS or GRAVELLY SANDS little or no fines
SAND-SILT-CLAY Mixtures, slight plasticity
SILTY SANDS or SAND-SILT Mixtures, sl. plasticity
SANDS or GRAVELLY SANDS little or no fines
SAND-SILT-CLAY Mixtures, plastic
SILTY GRAVELS, or GRAVEL-SAND-SILT Mixtures
SAND-SILT-CLAY Mixtures or CLAYEY SANDS, plastic to high pl.
SILTS and very fine SANDS slight or no plasticity
GRAVELS and GRAVEL-SAND Mixt little or no fines
LEAN CLAYS, SILTY CLAYS, slightly plastic to plastic
ELASTIC SILTS, Micaceous or Diatomaceous SILTS
FAT CLAYS, SILTY CLAYS highly plastic

STRESS LEVEL	MINIMUM	1	2	3	4	5	MAXIMUM
GROSS TONS	30	34	38	42	46	50	50
TIRE PSI	40	50	60	70	80	90	130

E. Exceptions. Proof rolling of the subgrade surface in embankment sections will not be required in any area where:

1. due to restrictions in available access and/or maneuvering space, use of the proof roller may damage adjacent work;

2. the proof roller will approach a culvert, pipe or other conduit closer than 5 feet in any direction.

GRASS MAINTENANCE

Maintenance work can also be contracted and the following excerpt on maintaining grass illustrates the format of suitable specifications for all ground maintenance. The example applies to upkeep at active Department of the Navy bases and thus has some major differences from long-term maintenance of covered waste cells. The frequency of maintenance activity is much less at a closed waste cell or site. Note that the paragraph numbers do not correlate with those suggested elsewhere in this document (Table 12 on page 36). The tabulation included midway in the excerpt can alternatively be included with plans that would ordinarily accompany these specifications.

6. GRASS MAINTENANCE

6.1 Lawn Aeration: Grass in area _____ shall be aerated during the period _____ through _____. A machine which removes 1/2-inch cores or which has renovating spoons to penetrate the soil at least 2 inches on a spacing of not more than 8 inches by 8 inches shall be used. If a coring machine is used, a drag mat shall be used to break up loose cores and spread soil. This work shall not be done when soil is extremely wet or extremely dry.

6.2 (Fertilizer)(and)(lime) shall be delivered to the site in the original, unopened containers bearing the manufacturer's guaranteed chemical analysis, name, trade name, or trademark and in conformance to state and federal law. In lieu of containers, fertilizer and lime may be furnished in bulk and a certificate indicating the above information shall accompany each delivery. The fertilizer shall be applied when blades of grass are dry.

AREA	ACRES	TIME OF APPLICATION	TYPE OF FERTILIZER	METHOD-OR-RATE OF APPLICATION	TOTAL AMOUNT REQUIRED

6.3 Renovation: Grass in areas shown on plan shall have thatch removed by verti-cutting during the period _____ through _____. Apply fertilizer at the rate of _____ pounds per 1,000 square feet and overseed, if desired, with _____ seed applied at the rate of _____ pounds per 1,000 square feet. Irrigation shall be done immediately.

6.4 Irrigation of Grass: Grass in areas _____ and _____ shall be irrigated with a uniform application of _____ inches of water when less than that amount of rain has been received the previous seven days. Water shall be applied at a rate which will not cause runoff. The Contractor shall provide and maintain a simple rain gage which has the approval of the Contracting Officer. The entire amount of water shall not be provided in one application. The Contractor shall provide information to the Contracting Officer on the application rate and degree of overlap required for uniform application for each type of irrigation equipment to be used. If irrigation system is electrically controlled, watering shall be done at night; otherwise, watering shall be done during earliest possible morning hours.

6.5 Weed Control: In grassed areas the Contractor shall control vegetation such as noxious weeds, vines, brush, or grass. If control is required, EPA-approved chemicals according to label directions will be used. Materials proposed for such use must have the prior approval of the station Navy-certified Pest Control Inspector or the Special Assistant for Applied Biology, _______________. Extreme caution shall be exercised to prevent spray drift from adversely affecting nearby desirable shrubs, trees, and grass. All such work shall be monitored under the direct and continuing supervision of a Navy-certified Pest Control Inspector. All pesticide usage under this contract shall be reported to the Contracting Officer on a monthly basis and provide all information which is required to be submitted on DD Form 1532.

6.6 Flower Beds: Flower beds in areas _____ shall be treated with an EPA-approved herbicide at the time of planting to control weed pulling.

6.7 Insect and Disease Control: The Contractor will not have the responsibility for insect and disease control but is requested to report infestations promptly to the Contracting Officer.